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ORIGINAL ARTICLES

THE GENUS *FUSARIUM*

V. *FUSARIUM UDUM* BUTLER, *F. VASINFECTUM* ATK. AND *F. LATERITIUM* NEES VAR. *UNCINATUM* WR.

BY

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(Received for publication on 16 April 1940)

(With Plates XXXIX-XLI)

INTRODUCTION

IN the preceding paper of this series [Padwick, Mitra and Mehta, 1940] it was shown that a considerable number of isolates of *Fusarium* causing wilt of cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*) are highly specialised as regards their host relations. It was early appreciated by the author that to have a sound understanding of the genus *Fusarium* the first essential is the systematic study under defined conditions of a large number of isolates, combined, where possible, with pathogenicity tests. The isolates referred to in the preceding paper formed the material for a study, in a systematic manner, of the morphology and cultural characters of these wilt-causing organisms.

CULTURAL CHARACTERS OF THE WILT-CAUSING FUNGI

The fungi were grown on the following media :—

(1) Potato dextrose agar, 2 per cent [Wollenweber *et al.*, 1925]
(2) Brown's agar [Brown, 1925]
(3) Brown's starch agar [Brown, 1925]
(4) Steamed rice [Wollenweber *et al.*, 1925]

All the cultures used in the pathogenicity test described in Part IV of this series were grown on agar slants of the above media, in triplicate, at 30°C. The work was done concurrently with starting the pathogenicity test. As it was seen that some of the cultures were non-pathogenic or failed to produce wilt, the number of cultures was reduced for the second study of cultural characters, at 20°C.

Observations on the colours produced in the aerial mycelium and on the surface of the substrate, or ' stroma ', were made on the 10th day and again on the 20th day of growth. The remaining notes were made on the 21st to 24th days.

Nothing would be gained by giving here all the data accumulated, but since a standard method of recording has been established for all *Fusarium* cultural studies, this may be briefly described. Standard typed forms are used, with a space for notes on every character commonly used in identifying *Fusaria*. In this way only is it possible to escape the criticism that can be

justly levelled against a great deal of the taxonomic work on this genus—namely, that certain characters which the worker may happen to think unimportant for the particular species concernedare neglected. Each character, such as colour of aerial mycelium, colour of surface of substrate, abundance of aerial mycelium, sclerotia, type of fruiting structures, type of conidia in pionnotes or sporodochia, type of conidia in aerial mycelium, etc. is recorded separately for each culture. The observations on all the cultures in the experiment, and on all the media, are recorded for one character at a time, and the next character is disregarded until the previous one has been completed for all the cultures. Thus the characters which have to be described in arbitrary terms are fairly comparable for each culture in the experiment and such terms as 'few', 'abundant', 'thin', 'thick', 'distinct', 'indistinct', 'rough', 'smooth', 'warty', etc. have a real significance, the personal factor being minimised as far as possible. Colours are all recorded according to the nomenclature of Ridgway [1912]. Conidial characters are examined in water mounts at a magnification of 600. In most cases the descriptions of the spores are accompanied by rough sketches, which are especially useful in indicating the degree of curvature. In cases where chlamydospores or other structures are not found, it is usual to examine two or three slides from each tube of the triplicate series before recording the structures as absent. It is usual to record the colours, the abundance of aerial mycelium, the presence or absence of sclerotia, and the type of chlamydospores on all media, but the characters requiring minute microscopic examination, chiefly the kinds of conidia, cannot always be described thus, and in this case it is the practice to complete the data for potato dextrose agar at least, as this medium has been found rather more reliable than the others, being the one most commonly associated with 'Normkulture'. Brown's media are often found disappointing in this respect.

In Table I are recorded in the most concise manner possible all the characters in which the various wilt fungi differed appreciably. The identity of each culture as *Fusarium udum* Butler (*F. Butleri* Wr.) [Butler, 1910] or *Fusarium vasinfectum* Atk. [Atkinson, 1892, with the help of the emended descriptions of Wollenweber and Reinking, 1935] may be concluded without great difficulty from this table.

Fungi causing cotton wilt

F 25.—Both in spore shape (tapering to a point or rounded) and colour on rice (dull violet black with potassium hydroxide and deep hellebore red with hydrochloric acid) this culture is typical of *Fusarium vasinfectum*.

F 147.—The spores of this culture are again typical of *Fusarium vasinfectum*. There is a slight drabness of colour not quite normal for this species.

Fungi causing pigeon-pea wilt

F 2.—With its hooked macrospores borne in a pionnotal slime, and its brilliant yellow and orange hues on rice, this fungus is extraordinarily reminiscent of *F. udum* as described by Butler, but has no true chlamydospores.

eptation of spores on per cent P. D. A. at 30°C.	Apices of long spores at 30°C.	Colours on rice at 30°C.	Sporing structures on 2 per cent P. D. A. at 30°C.	Media with chlamydo-spores at 30°C. (terminal or intercallary (Tor I). Abundance)
0 -3 on rice)	Tapering to point or rounded	Perilla purple	No characteristic sporing structures	P. D. A. (T. and I. few) Brown's agar (T. and I. few) Brown's starch agar (T. and I rare)
0—1 -2 on Brown's starch ar)	......	Dresden brown	Do.	P. D. A.) (T. and I. moderate) Brown's agar (T. and I. moderate) Brown's starch agar (I. rare)
0	......	Picric yellow and carnelian red	Do.	None... Hyphal swellings only observed on Brown's starch agar
0—5	Sharply pointed, hooked foot-celled	Cinnamon brown and hydrangea pink	Thin pionnotal layer	P. D. A. (T. and I. moderate) Hyphal swellings only on Brown's agar and Brown's starch agar
0—1 ores very rare)	......	Cinnamon brown and pale vinaceous pink	No characteristic sporing structures	P. D. A. (T. and I. rare) Brown's starch agar (T. and I. few)
0	......	Picric yellow and apricot orange	Do.	P. D. A. (T. and I. moderate)
0—3	Rounded, often bent	Do.	Pale pinkish cinnamon pionnotal slime	P. D. A. (T. and I. moderate)
0—3	Do.	Do.	Do.	P. D. A. (T. and I. moderate) Brown's starch agar (T. rare)
0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar and Brown's starch agar
0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar
0—3	Do.	Do.	Do.	Do.
0—3	Hooked	Do.	Tilleul buff pionnotal slime	None.
0 septate on Brown's)	......	Cream buff, apricot buff, apricot orange and chestnut brown	Pale pinkish cinnamon pionnotal slime	Do.
0	......	Do.	Do.	P. D. A. (T. and I. few). Brown's starch agar (T. rare)
0 septate on Brown's)	......	Pale ochraceous buff, apricot orange and chestnut brown	Do.	None.
0	......	Do.	Do.	Brown's agar (T. and I. moderate)

Culture	Host plant	Sclerotia at 20°C.	Septation of spores on 2 per cent P. D. A. at 20°C.	Apices of long spores at 20°C.	Colours on rice at 20°C.
F 171	Pigeon-pea .	None	0—2	Hooked . . .	Naphthalene yellov antimony yellow, Indi purple
F 172	Do. .	Do.	0—6	Do. . . .	Barium yellow, apr cot orange, du purplish black
F 173	Do .	Do.	0—5	Do. . . .	Barium yellow, warı buff, anthracen purple
F 174	Do .	Do.	0—5	Do. . . .	Citron yellow an apricot orange
F 175	Do .	Do.	1—5	Do. . . .	Citron yellow an mustard yellow
F 176	Do .	Do.	1—3	Do. . . .	Barium yellow an mustard yellow
F 13	Do .	Do.	0—1	......	Amber yellow an apricot orange
F 15	Do	Do.	0—3	Hooked . . .	Barium yellow and apı cot orange
F 18	Sunn-hamp .	Do.	0—5	Sometimes hooked . .	Citron yellow and ma orange
F 19	Do .	Do	0—3	Rounded . . .	None
F 26	Do .	Do.	0—1	......	Barium yellow and apı cot orange
F 166	Do .	Do.	0—1	......	None
F 167	Do ? .	......	...	......	...
F 168	Do .	None	0—2	......	None
F 169	Do ? .	Do.	0—1	......	Anthracene purple
F 170	Do ? .	......	...	......	......

Table I

Morphological and cultural characters of fungi causing wilt of cotton, pigeon-pea and sunn-hemp

Culture	Host plant	Sclerotia at 20°C.	Septation of spores on 2 per cent P. D. A. at 20°C.	Apices of long spores at 20°C.	Colours on rice at 20°C.	Colours on rice with 2 per cent KOH at 20°C.	Colours on rice with 2 per cent HCl at 20°C.	Sporing structures on 2 per cent P. D. A. at 20°C.	Media with chlamydospores at 20°C. (Terminal or intercallary (tor I). Abundance)	Sclerotia at 30°C.	Septation of spores on 2 per cent P. D. A. at 30°C.	Apices of long spores at 30°C.	Colours on rice at 30°C.	Sporing structures on 2 per cent P. D. A. at 30°C.	Media with chlamydospores at 30°C. (terminal or intercallary (Tor I). Abundance)
F 25	Cotton .	None	0—6	Tapering to point .	Dark hellebore red and hyssop violet	Dull violet black .	Deep hellebore red .	No characteristic sporing structures, but pinkish vinaceous spore masses on other media	Brown's agar (T. and I. moderate) Brown's starch agar (I. rare)	None	0 (0—3 on rice)	Tapering to point or rounded	Perilla purple .	No characteristic sporing structures	P. D. A. (T. and I. few) Brown's agar (T. and I. few) Brown's starch agar (T. and I rare)
F 147	Do.	On rice. Up to 2 mm. diameter. Blackish brown.	0 (0—3 on rice)	(On rice, bluntly pointed)	Light brownish drab	Light brownish drab	Deep purple drab .	No characteristic sporing structures	P. D. A. (T. and I. moderate). Brown's agar (T. and I. moderate). Brown's starch agar (I. few). Rice (T. and I. abundant)	Do.	0—1 (0—2 on Brown's starch agar)	......	Dresden brown .	Do.	P. D. A.) (T. and I. moderate) Brown's agar (T. and I. moderate) Brown's starch agar (I. rare)
F 2	Pigeon-pea .	None	0—3	Hooked . . .	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	Pale pionnotal slime .	None. Hyphal swellings only observed on Brown's agar and potato dextrose agar	Do.	0	......	Picric yellow and carnelian red	Do.	None... Hyphal swellings only observed on Brown's starch agar
F 3	Do. ?	......	...	......	......					Do.	0—5	Sharply pointed, hooked foot-celled	Cinnamon brown and hydrangea pink	Thin pionnotal layer .	P. D. A. (T. and I. moderate) Hyphal swellings only on Brown's agar and Brown's starch agar
F 4	Do. ?	......	...	......	......					Do.	0—1 (Spores very rare)	......	Cinnamon brown and pale vinaceous pink	No characteristic sporing structures	P. D. A. (T. and I. rare) Brown's starch agar (T. and I. few)
F 5	Do.	None	0—4	Rounded, rarely slightly hooked	Light seal brown, mars violet, hazel	Taupe brown .	Dark livid brown .	No characteristic sporing structures	P. D. A. (T. and I. few). Hyphal swellings only observed on Brown's agar and rice	Do.	0	......	Picric yellow and apricot orange	Do.	P. D. A. (T. and I. moderate)
F 6	Do.	Do.	0—5	Hooked . . .	Sea-shell pink and naphthalene yellow	Sea-shell pink and naphthalene yellow	Sea-shell pink and naphthalene yellow	Vinaceous cinnamon pionnotal slime	None	Do.	0—3	Rounded, often bent .	Do.	Pale pinkish cinnamon pionnotal slime	P. D. A. (T. and I. moderate)
F 7	Do.	Do.	0—3	Do. . . .	Trace of naphthalene yellow	Trace of naphthalene yellow	Trace of naphthalene yellow	Some isolated hydrangea pink spore masses	Do.	Do.	0—3	Do.	Do.	Do.	P. D. A. (T. and I. moderate) Brown's starch agar (T. rare)
F 10	Do.	Do.	0—1	Do. . . .	Naphthalene yellow	Naphthalene yellow .	Naphthalene yellow	No characteristic spore masses, but some isolated salmon-buff spore masses on other media	Do.	Do.	0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar and Brown's starch agar
F 11	Do.	Do.	0—3	Do. . . .	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	Abundant salmon-buff spore masses	P. D. A. (T. and I. abundant). Hyphal swellings only on Brown's agar and Brown's starch agar	Do.	0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar
F 12	Do.	Do.	1—5	Do . . .	Naphthalene yellow	Naphthalene yellow .	Naphthalene yellow	Do.	Hyphal swellings only on P. D. A. and Brown's agar	Do.	0—3	Do.	Do.	Do.	Do.
F 59	Do.	Do.	0—6	Do. . .	Citron yellow apricot orange, anthracene purple	Citron yellow, apricot orange, anthracene purple	Citron yellow, apricot orange, anthracene purple	Ivory yellow spore masses	P. D. A. (I. few). Rice (T. and I. few)	Do.	0—3	Hooked	Do.	Tilleul buff pionnotal slime	None.
F 137	Do.	On P. D. A. Up to 5 mm. diam. Covered with white mycelium	0—3	Do. . . .	Barium yellow, apricot buff, naphthalene violet, chestnut brown	Barium yellow, apricot buff and dull violet black	Barium yellow, apricot buff, naphthalene violet, chestnut brown	Vinaceous pink spore masses	P. D. A. (T. and I. few) .	Do.	0 (0—1 septate on Brown's agar)	......	Cream buff, apricot buff, apricot orange and chestnut brown	Pale pinkish cinnamon pionnotal slime	Do.
F 139	Do.	Do.	0—3	Do. . . .	Anthracene purple .	Dull violet black .	Anthracene purple .	Salmon buff spore masses	Brown's starch agar (T. and I. abundant). Hyphal swellings only on Brown's agar.	Appeared to be forming pale fleshy sclerotia on rice	0	......	Do.	Do.	P. D. A. (T. and I. few). Brown's starch agar (T. rare)
F 164	Do.	None	0—1 (0—3 rice)	(Hooked on rice) .	Vinaceous and dark mineral red	Dull violet black .	Vinaceous and dark mineral red	Ochraceous buff spore masses	P. D. A. (T. and I. moderate). Brown's starch agar (T. and I. moderate). Rice (T. and I. abundant). Hyphal swellings only on Brown's agar.	None	0 (0—1 septate on Brown's agar)	......	Pale ochraceous buff, apricot orange and chestnut brown	Do.	None.
F 165	Do.	On P. D. A. Up to 5 mm. diam. Covered with white mycelium	0—3	Hooked . . .	Amber yellow, apricot orange, citron yellow, corinthian pink	Amber yellow, apricot orange, citron yellow, corinthian pink.	Amber yellow, apricot orange, citron yellow, corinthian pink	Light vinaceous cinnamon spore masses	P. D. A. (T. and I. few) .	Appeared to be forming large pale fleshy sclerotia on rice	0	......	Do.	Do.	Brown's agar (T. and I. moderate)

TABLE I—contd.

Culture	Host plant	Sclerotia at 20°C.	Septation of spores on 2 per cent P. D. A. at 20°C.	Apices of long spores at 20°C.	Colours on rice at 20°C.	Colours on rice with 2 per cent KOH at 20°C.	Colours on rice with 2 per cent HCl at 20°C.	Sporing structures on 2 per cent P. D. A. at 20°C	Media with chlamydospores at 20°C. (terminal or intercallary (Tor I). Abundance)	Sclerotia at 30°C.	Septation of spores on 2 per cent P. D. A. at 30°C.	Apices of long spores at 30°C.	Colours on rice at 30°C.	Sporing structures on 2 per cent P. D. A. at 30°C.	Media with chlamydospores at 30°C.* (terminal or intercallary (Tor I). Abundance)
F 171	Pigeon-pea .	None	0—2	Hooked . . .	Naphthalene yellow, antimony yellow, Indian purple	Naphthalene yellow, antimony yellow, dull violet black	Naphthalene yellow, antimony yellow, Indian purple	No characteristic sporing structures, but salmon buff spore masses on other media	Brown's agar (T. and I. moderate).	None	0	......	Mustard yellow, apricot orange, chestnut brown and coral pink	Pale pinkish cinnamon pionnotal slime	Hyphal swellings only on Brown's agar
F 172	Do. .	Do.	0—6	Do. . . .	Barium yellow, apricot orange, dull purplish black	Barium yellow, apricot orange, dull violet black	Barium yellow apricot orange, dull violet black	Salmon buff pionnotal slime	P. D. A. (T. rare) Brown's agar (T. rare) Hyphal swellings only on Brown's starch agar	Do.	0	......	Do.	Do.	None
F 173	Do .	Do.	0—5	Do. . . .	Barium yellow, warm buff, anthracene purple	Barium yellow, warm buff, dull violet black	Barium yellow, warm buff, anthracene purple	Do.	Hyphal swellings only on Brown's agar and rice	Do.	0—2 (0—3 septate on Brown's starch agar)	Rounded, often bent .	Do.	Do.	P. D. A. (T. rare) Brown's agar (T. and I abundant)
F 174	Do .	Do.	0—5	Do. . . .	Citron yellow and apricot orange	Citron yellow and apricot orange	Citron yellow and apricot orange	Do.	Hyphal swellings only on Brown's starch agar	Do.	0 (0—1 septate on Brown's starch agar)	......	Ochraceous buff, dark mineral red, apricot orange	Do	None
F 175	Do .	Do.	1—5	Do. . . .	Citron yellow and mustard yellow	Citron yellow and mustard yellow	Citron yellow and mustard yellow	Do.	Hyphal swellings only on P. D. A. and Brown's agar	Do.	0 (0—2 septate on Brown's agar and Brown's starch agar)	......	Do.	Do.	Do.
F 176	Do .	Do.	1—3	Do. . . .	Barium yellow and mustard yellow	Barium yellow and mustard yellow	Barium yellow and mustard yellow	Do.	P. D. A. (T. and I. few). Brown's agar (T. and I. rare). Hyphal swellings only on Brown's starch agar	Do.	0 (0—2 septate on Brown's agar)	......	Do.	Do.	Do.
F 13	Do .	Do.	0—1	......	Amber yellow and apricot orange	Amber yellow and apricot orange	Amber yellow and apricot orange	No characteristic sporing structures	P. D. A. (T. and I. moderate). Brown's agar (T. rare). Brown's starch agar (T. and I. abundant). Rice (I. rare)	Do.	0 (0—1 septate on Brown's agar)	......	Picric yellow and apricot orange	No characteristic sporing structures.	P. D. A. (T. and I. rare) Brown's starch agar (T. and I. few)
F 15	Do	Do.	0—3	Hooked . . .	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	No characteristic sporing structures, but pale pinkish cinnamon spore masses on other media	Brown's starch agar (T. and I. few). Hyphal swellings only on P. D. A	Appeared to be forming large pale fleshy sclerotia on rice.	0	......	Naples yellow, Indian red and cinnamon rufous	Pale pinkish cinnamon pionnotal slime	None.
F 18	Sunn-hamp .	Do.	0—5	Sometimes hooked . .	Citron yellow and mars orange	Citron yellow and mars orange	Citron yellow and mars orange	No characteristic sporing structures	P. D. A. (T. and I. rare). Hyphal swellings only on Brown's agar	None	0 (0—2 septate on Brown's agar)	......	Mustard yellow and apricot orange	No characteristic sporing structures	Do.
F 19	Do .	Do	0—3	Rounded . . .	None	None	None	Do	None	Do	0—3	Bluntly pointed .	Dark vinaceous .	Scattered pionnotes	Do.
F 26	Do .	Do.	0—1	......	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	Do.	P. D. A. (T. and I. few). Hyphal swellings only on Brown's agar.	Do.	0	......	Pinard yellow and apricot orange	No characteristic sporing structures	Brown's agar (T. and I. abundant) Brown's starch agar (T. and I. abundant)
F 166	Do .	Do.	0—1	......	None	None	None	Pale pionnotal slime	P. D. A. (T. and I. moderate). Brown's agar (T. and I. moderate). Rice (T. and I. moderate)	Appeared to be forming. dark sclerotia on P D. A.	0	......	Pale vinaceous pink, honey yellow and apricot orange	Do.	P. D. A. (T. and I. abundant)
F 167	Do ? .	......	...	......	...	......	......	......	......	None	0—3	Bluntly pointed .	Pale vinaceous drab .	Ivory yellow sporodochia	Brown's agar (T. and I. abundant)
F 168	Do .	None	0—2	......	None	None	None	Light vinaceous cinnamon spore masses	P. D. A. (T. and I. few). Brown's agar (T. and I. abundant). Rice (T. and I. few).	Appeared to be forming dark sclerotia on P. D. A.	0	......	Amber yellow and apricot orange	No characteristic sporing structures	P. D. A. (T. and I few). Brown's agar (T. and I. few)
F 169	Do ? .	Do.	0—1	......	Anthracene purple .	Dull violet black . .	Anthracene purple .	No characteristic sporing structures	P. D. A. (T. rare). Brown's agar (T. and I. moderate)	Appeared to be forming dark sclerotia on P. D. A. and fleshy sclerotia up to 3 mm. diam. on Brown's starch agar.	0—3	Bluntly pointed .	Dark vinaceous brown .	Small ivory yellow sporodochia	Brown's agar (T. and I. abundant)
F 170	Do ? .	......	...	......	......	......	......	......	......	None	No spores	......	Mummy brown . .	No characteristic sporing structures	Brown's agar (T. and I. abundant) Brown's starch agar (T. and I. moderate)

*No observations were made of chlamydospores on rice at 30°C.

F 5.—The spores of this fungus are not always hooked and it has none of the characteristic pionnotes of *F. udum*. Its brown hues on rice at 20°C. are not typical of *F. udum*, but at 30°C. on rice it has the unmistakable picric yellow and apricot orange colours. The terminal and intercallary chlamydospores are true to type.

F 6.—The hooked spores borne in vinaceous cinnamon or pale pinkish cinnamon pionnotal slime, as well as the picric yellow and apricot orange colours on rice at 30°C. give this fungus the unmistakable appearance of *F. udum*. The chlamydospores are true to type.

F 7.—Typical *F. udum*.

F 10.—Typical *F. udum* except in lacking chlamydospores.

F 11.—Typical *F. udum*.

F 12.—Typical *F. udum* except in lacking chlamydospores.

F 59.—The hooked spores, the colour on rice at 30°C. and the chlamydospores, are typical of *F. udum*. The pionnotes are paler. A striking characteristic is the production of an anthracene purple pigment on rice at 20°C.

F 137.—The hooked spores in pionnotes and the chlamydospores are typical of *F. udum*. The cream buff and chestnut brown colours on rice at 30°C. and the naphthalene violet colour at 20°C. do not conform with the original description of *F. udum*.

F 139.—True to *F. udum* in all other respects, the culture produces a striking anthracene purple pigment on rice at 20°C. becoming dull violet black with potassium hydroxide and unaltered with dilute hydrochloric acid.

F 164.—Closely resembles F 139.

F 165.—Resembles F 139 but produces corinthian pink colour instead of anthracene purple on rice at 20°C.

F 171.—Similar to F 139.

F 172.—Similar to F 139 but chlamydospores terminal and rare.

F 173.—Similar to F 139.

F 174.—Typical *F. udum* except in lacking chlamydospores and producing some dark mineral red pigment on rice at 30°C.

F 175.—Similar to F 174.

F 176.—Typical *F. udum* except in producing some dark mineral red pigment on rice at 30°C.

F 13.—In colour production and chlamydospores true to *F. udum*, but producing only microspores and no pionnotes.

F 15.—Typical *F. udum* except in producing Indian red and cinnamon rufous colours on rice at 30°C.

Fungi causing sunn-hemp wilt

F 18.—In this culture the hooked spores are exceptional and they are not produced in a pionnotal slime, but in other respects the culture is true to *F. udum*.

F 19.—The apices of the spores are rounded or bluntly pointed. No colours are formed on rice at 20°C. and at 30°C. the dark vinaceous colour of *F. vasinfectum* occurs. There are no chlamydospores. Microconidia are produced in false heads on P. D. A. at 30°C.

F 26.—The colours and chlamydospores are typical of *F. udum.* No long spores are produced and pionnotes are absent.

F 166.—The colours are fairly typical of *F. udum* at 30°C., but with the addition of some pale vinaceous pink. Colour is lacking at 20°C. Chlamydospores are also typical. No long spores are produced and the pionnotal slime of microspores is pale instead of bright coloured.

F 168.—The colours are typical of *F. udum* at 30°C. but lacking at 20°C. Chlamydospores are correct for *F. udum.* Long spores are lacking but microspores are produced in typical pionnotal slime.

Fungi causing a low percentage of wilt

PIGEON-PEA

F 3.—Only three plants were wilted by this organism. The colours produced are nearer those of *F. vasinfectum* than *F. udum.* The sharply pointed spores and the well-developed foot-cell are not like *F. udum.*

F 4.—The colours are not typical of *F. udum* but as long spores are lacking and even microspores are rare, and the fungus was not grown at 20°C., a decision on identity of the fungus cannot now be reached.

SUNN-HEMP

F 167.—In colour and spore shape this culture much more closely resembles *F. vasinfectum* than *F. udum.* Microconidia are produced in false heads on P. D. A. at 30°C.

F 169.—The spores are bluntly pointed. The bright yellow and orange colours of *F. udum* are lacking. The anthracene purple and dark vinaceous brown colours and the reaction to potassium hydroxide and hydrochloric acid are those of the purple-pigmented isolates of *F. udum* rather than the purples typical of *F. vasinfectum*, which become distinctly red with hydrochloric acid. Microconidia are produced in false heads on P. D. A. at 30°C.

F 170.—The culture produces no spores and the colours are typical of neither *F. vasinfectum* nor *F. udum.*

Cultures F 25 and F 147, causing cotton wilt, may be regarded as *F. vasinfectum* or one of its varieties or forms. All the cultures causing high percentage of pigeon-pea wilt are *F. udum* provided the form circle is enlarged sufficiently to include those forms producing anthracene purple or similar pigments, which change to dull violet black with potassium hydroxide, certain forms producing no chlamydospores, and forms producing few or no long-septate spores (certain of these produced them in a later experiment),

This is a species with wide variation. If all these isolates are not to be regarded as *F. udum*, and instead specific rank is given to such characters as presence or absence of the anthracene purple pigment, presence or absence of terminal and intercallary chlamydospores, relative proportions of short and long spores, presence or absence of a pionnotal slime, of sclerotia and so on, there will be almost as many species as there are isolates.

It seems reasonable to regard also as *F. udum*, the cultures F 18, F 26, F 166 and F 168 which cause wilt of sunn-hemp, and a list of some of the more variable characters of this species, evident in the isolates here studied, is as follows :

Colours on steamed rice

Barium yellow, picric yellow, naphthalene yellow, citron yellow, amber yellow, antimony yellow, mustard yellow, Naples yellow, pinard yellow, honey yellow, cream buff, apricot buff, pale ochraceous buff, warm buff, apricot orange, mars orange, light seal brown, chestnut brown, cinnamon rufous, hazel, coral pink, corinthian pink, sea-shell pink, pale vinaceous pink, vinaceous, carnelian red, Indian red, dark mineral red, mars violet, Indian purple, anthracene purple, naphthalene violet, dull purplish black. Some cultures may lack colour entirely. The most striking colours are the bright yellows and oranges.

Pionnotes

Pionnotes may be absent, discrete or covering the surface of the medium as a thick slime, with the following colours :

Ivory yellow, light vinaceous cinnamon, vinaceous cinnamon, pale pinkish cinnamon, salmon buff, ochraceous buff, tilluel buff, hydrangea pink, vinaceous pink.

Conidia

Conidia may vary from entirely 0-septate spores in some cultures to 0-6 septate in others. The longer spores are usually hooked at the end, the shorter ones are curved and sometimes bent almost at right angles in the middle.

Chlamydospores

Chlamydospores may be absent, few or abundant, but when present are both terminal and intercallary, and may be in chains or in groups.

Sclerotia

Sclerotia large and fleshy, either pale or dark in colour.

The isolates F 3, F 4 and F 170 have been insufficiently studied. Cultures F 19, F 167 and F 169, which cause a certain amount of sunn-hemp wilt, are quite different from both *F. udum* and *F. vasinfectum*. The bright yellow and orange colours of *F. udum* are lacking, the spores are never hooked, and are thick (the mean width of 50 spores of F 169 was nearly 40 per cent greater than the width of the widest spores of *F. udum* and *F. vasinfectum*, of which some hundreds were measured).

The author was impressed by the likeness of many of the cultures which can best be regarded as typical *F. udum* to the fungus *Fusarium lateritium*

var. *uncinatum* Wr. as described by Wollenweber [1938]. According to him these fungi differ in the following characters :

F. udum	*F. lateritium* var. *uncinatum*
Spores sickle-shaped	Spores hooked
Produces 'orange-bis' conidia.	Produces salmon-coloured conidia
Produces orange colour on steamed rice	Produces orange and yellow on steamed rice
Produces terminal chlamydospores	Produces no terminal chlamydospores
Belongs to section *Elegans*	Belongs to section *Lateritium*

A glance at Butler's original drawings will show at once that, although many of his spores are sickle-shaped, several are distinctly hooked. It is the shorter spores that are sickle-shaped, the longer ones hooked, and some of the cultures studied by the author have been found to produce both kinds.

Butler described the pionnotal stage as 'salmon-pink' only occasionally, on rice, orange-red. They are thus like those of *F. lateritium* var. *uncinatum*. It will be seen that the cultures examined varied considerably on rice. But a vital distinction should be in the chlamydospores. All the cultures described here either produced both terminal and intercallary chlamydospores or produced none at all. It is characteristic of the section *Lateritium* that its members produce no terminal chlamydospores. Wollenweber [1938], however, stated of *F. lateritium* var. *uncinatum* that 'The chlamydospores form, in contrast to *Elegans*-Fusaria, *if one disregards occasional exceptions** not terminally, but intercallary, more seldom single than in chains, and sometimes in clusters'.

Relationship between *F. vasinfectum* Atk., *F. udum* Butl., *F. lateritium* Nees var. *uncinatum* Wr. and the doubtful forms

A culture of *F. lateritium* Nees var. *uncinatum* Wr. was secured from the Centraalbureau voor Schimmelcultures, Baarn. It was considered necessary to include in the comparison typical cultures of *Fusarium vasinfectum* and its varieties and forms. These also were obtained from the Centraalbureau.

The final test of the validity of *F. udum* as a species would be to obtain an isolate of the fungus from Butler's original material in the Herbarium Crypt. Ind. Orient. His original collection from Dehra Dun and in addition some plants artificially inoculated by him were available, and attempts were made to isolate the fungus. They were unsuccessful and the fungus is probably dead. There is no culture of *F. udum* which has descended from Butler's type culture. The herbarium specimens are unsuitable for comparison. We are obliged to rely on his written description.

F. udum, as stated above, seemed to differ from *F. lateritium* var. *uncinatum* only in regard to chlamydospores, the latter fungus belonging to a group not producing terminal chlamydospores. It was therefore a matter of surprise when, on examining the type culture received from Baarn, it was found to have a considerable number of terminal as well as intercalary chlamydospores.

Table II summarises the major differences in cultural characters of a selection of the more variable forms of *F. udum*, *F. lateritium* var. *uncinatum*

*The italics are the author's.

TABLE II

Morphological and cultural characters of Fusarium vasinfectum *Atk.*, F. udum *Butl. and* F. lateritium *Nees var.* uncinatum *Wr., grown for 21 to 23 days at 20°C.*

Culture	Species	Septation of spores on 2 per cent P. D. A.	Shape of spores	Colours on rice	Media with chlamydospores
F 21	*F. vasinfectum* Atk. (from C. B. S.)	0—3	Ovoid to spindle, not foot-celled	Rocellin purple and neutral red	None
F 186	*F. vasinfectum* Atk. f. 1 Wr.	0—3	Ovoid to spindle or slightly curved, not-foot-celled	Rhodonite pink	P. D. A. (T. and I. abundant)
F 190	*F. vasinfectum* Atk. f. 2. Wr. et Rkg. (from C. B. S.)	0	Ovoid to spindle	Do.	P. D. A. (T. and I. moderate)
F 187	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) Wr. (from C. B. S.)	0—2	Ovoid to spindle or slightly curved, not foot-celled	Dull violet black and neutral red	P. D. A. (T. and I. few)
F 188	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) f. 1. (Lk. et Bail.) Wr. (from C. B. S.)	0	Ovoid to spindle	None	P. D. A. (T. and I. moderate) Rice (T. and I. moderate)
F 189	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) f. 2 (Lk. et Bail.) Wr. (from C. B. S.)	0—3	Ovoid to spindle or slightly curved, not foot-celled	Neutral red	P. D. A. (T. and I. moderate) Rice (T. and I. few)

TABLE II—*contd.*

Culture	Species	Septation of spores on 2 per cent P. D. A.	Shape of spores	Colours on rice	Media with chlamydospores
F 191	*F. vasinfectum* Atk. v. *lutulatum* (Sherb.) Wr. (from C. B. S.)	0—2	Ovoid to spindle or slightly curved, not foot-celled	Rhodonite pink	P. D. A. (T. and I. few)
F 25	*F. vasinfectum* Atk. (from cotton, Bombay)	0—3	Ovoid to spindle, not foot-celled	Neutral red	P. D. A. (T. few)
F 169	Section Martiella ?	3	Slightly curved, with rounded ends, not foot-celled	Dark livid brown	P. D. A. (T. and I. moderate) Rice (T. and I. abundant)
F 19	Do.	0—3	Ovoid to spindle or slightly curved, not foot-celled	Ageratum violet	None
F 26	*F. udum* Butl. (Sunn-hemp)	0	Ovoid to spindle	Barium yellow and apricot orange	P. D. A. (T. and I. few)
F 166	*F. udum* Butl. (Sunn-hemp)	0—6	Ovoid to spindle or sickle or slightly curved, strongly hooked, not foot-celled	Amber yellow and apricot orange	Rice (T. and I. moderate)
F 2	*F. udum* Butl. (Pigeon-pea)	0—3	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Citron yellow and apricot orange	None

F 6	Do.	0—several	Ovoid to pindle or sickle or slightly curved, strongly hooked, not foot-celled	Citron yellow and traces of salmon buff	Hyphal swellings only on P. D. A.
F 10	Do.	0—several	Do.	Do.	None
F 59	Do.	0—3	Ovoid to spindle or sickle or slightly curved, strongly hooked, occasionally slightly foot-celled	Barium yellow, apricot orange and dark livid brown	Do.
F 174	Do.	0—several	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Barium yellow and apricot orange	P. D. A. (T. and I. few) Rice (T. rare)
F 185	***F. lateritium*** Nees v. ***uncinatum*** Wr. (from C. B. S.)	0—4	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Barium yellow, apricot orange and Hay's russet	P. D. A. (T. and I. abundant) Rice (T. and I. abundant)

and *F. vasinfectum* with its varieties and forms, when grown on potato dextrose agar and steamed rice at 20°C. Plates XXXIX and XL give an idea of the range of colours produced on steamed rice by the three species. Camera lucida drawings of typical conidia are figured in Plate XLI, which also shows the development of terminal and intercallary chlamydospores of *F. lateritium* var. *uncinatum*.

Discussion

Butler [1926] decided that *Fusarium udum*, which he had described earlier [Butler, 1910] as the cause of wilt of pigeon-pea, is a synonym of *Fusarium vas infectum*. His description [Butler, 1910] of *Fusarium udum* was as follows :

'Mycelium parasitic within the roots of the host plant or saprophytic and then creeping, hyphae hyaline, slender, much branched, usually with little aerial growth ; microconidia of the *Cephalosporium* type, produced successively on the ends of short simple or clustered conidiophores and remaining bound in a drop of liquid after abjunction, unicellular or with one or more septa, elliptical or falcate, hyaline singly, salmon pink in mass, occasionally developing from the surface of minute spherical stromata and then of the *Tubercularia* type, 5-15 × to 2-4μ in diameter ; microconidial stage in culture usually moist and bacteria-like, white to salmon-pink, occasionally (on rice) orange red, never green or purple ; macroconidia of the *Fusarium* type, formed as the microconidia but on shorter conidiophores and becoming free as soon as abjuncted, falcate 3- to 5-septate, hyaline, 15-50 × 3-5μ in diameter, usually late in appearing ; chlamydospores, round or oval, rather thick-walled, hyaline, sometimes in short chains, 5 to 10μ in diameter.

Parasitic in roots of *Cajanus indicus* and saprophytic in soil, India.'

Butler's argument [1926] for regarding *F. udum* as a synonym of *F. vasinfectum* was of a rather indirect nature. The work described was done with cotton and *Sesamum* wilt fungi, not with the pigeon-pea organism, so that the comparison was between the *Sesamum* fungus and *F. vasinfectum* of cotton, and the conclusion as far as it relates to *F. udum* appears to be indirect and to rest on the statement : 'Furthermore, I have vainly endeavoured to find a true distinguishing character between the *Sesamum* fungus and *F. udum*, described by me in 1910 as the cause of the pigeon-pea wilt in India.'

The argument runs as follows :

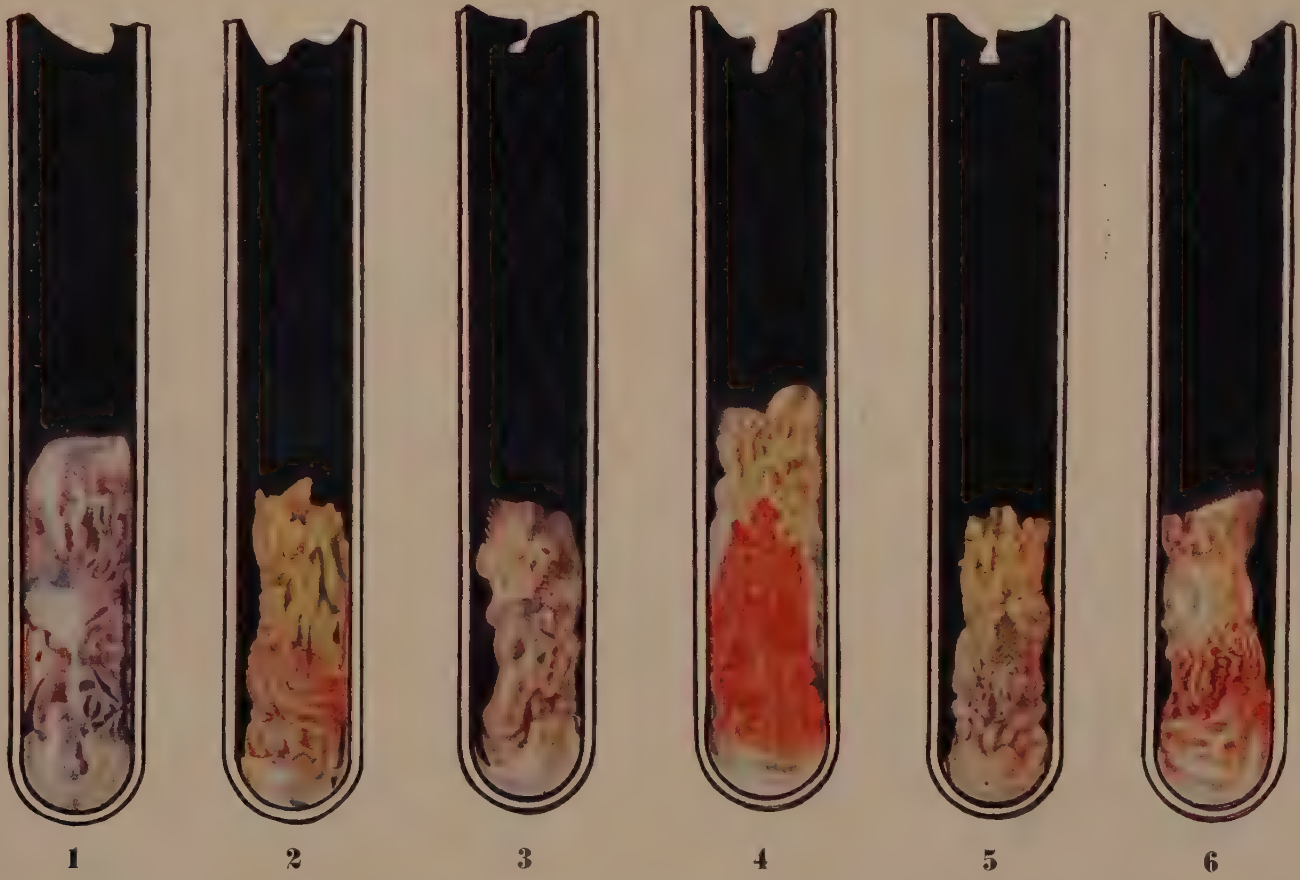
'Small has recently studied in great detail what he considers to be *F. udum*, which he found to be attacking a number of different plants in Uganda [*Kew Bull.*, 1920, p. 321 ; 1922, p. 269 ; 1925, p. 118]. Hence, though in India the strain of *F. udum* parasitic on pigeon-pea seems to be restricted to that host, in Uganda the morphologically and culturally similar fungus is capable of attacking not only pigeon-pea but a considerable number of other plants, and this strengthens the possibility that the sesamum parasite may be merely another strain of the same species.

Fusarium udum itself was named without prejudice to the question whether it had not been previously included amongst the named members of the genus. The chief diagnostic characters were the pionnotal type of sporulation, the flesh to salmon-pink colour on many media with absence of blue colours, and the tubercular stromata on potato and plantain. Subsequent isolations at Pusa, however, showed that the first of these characters was not constant, some strains giving a copious aerial mycelium on agar slants. Nodular sclerotia also are now known to be commonly produced by many members of the genus and occur in both *Fusarium cubense* and the sesamum parasite in which they are blue on potato but gradually turn pink if placed in lactic acid. Bessy's conclusions that the red and blue colours are only chemical modifications of the same pigment has been substantiated by subsequent investigators, and there seems every probability that the blue or violet colours developed in *F. cubense* and the sesamum fungus could also be produced by *F. udum* on suitable media. Small indeed [*Kew Bull.*, 1922, p. 282] obtained a pale blue pigment in his strain in two cultures.

CULTURES OF *FUSARIUM VASINFECTUM* GROWN ON STEAMED RICE
(20 TO 29 DAYS AT 30° C.)

1. F 21—*F. vasinfectum* Atk. 2. F 186—*F. vasinfectum* Atk. *f.1* Wr. 3. F 190—*F. vasinfectum* Atk. *f.2* Wr. et Rkg. 4. F 187—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) Wr. 5. F 188—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) *f.1* (Lk. et Bail.) Wr. 6. F 189—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) *f.2* (Lk. et Bail) Wr. 7. F 191—*F. vasinfectum* Atk. var. *lutulatum* (Sherb.) Wr.

CULTURES OF *FUSARIUM* PATHOGENIC ON PIGEON-PEA AND SUNN-HEMP, GROWN ON STEAMED RICE (22 TO 31 DAYS AT 30° C)



1. F 169—A weak parasite of sunn-hemp (Section Martiella ?); 2. F 26—*F. udum* Butl. var. *crotalariae* n. v.; 3. F 166—*F. udum* Butl. var. *crotalariae* n. v.: 4. F 2—*F. udum* Butl. var. *cajani*; n. v. 5. F 10—*F. udum* Butl. var. *cajani* n. v.; 6. F 185—*F. lateritium* Nees var. *uncinatum* Wr. (*F. udum* Butl.)

CONIDIA AND CHLAMYDOSPORES OF *FUSARIUM UDUM* AND *F. VASINFECTUM* GROWN ON POTATO DEXTROSE AGAR (21 TO 23 DAYS AT 20°C) (×640)

1. Early stages of terminal and intercallary chlamydospore formation by F 185—*F. lateritium* Nees. var. *uncinatum* Wr. (*F. udum* Butl.) 2. Late stages of the same. 3. Pionnotal spores of the same. 4. Pionnotal spores of F 166—*F. udum* Butl. var. *crotalariae* n. v. 5. Pionnotal spores of F 59—*F. udum* Butl. var. *cajani* n. v. 6. Pionnotal spores of F 174—*F. udum* Butl. var. *cajani* n. v. 7. Spores from agar surface, F 21—*F. vasinfectum* Atk. 8. Spores from agar surface, F 186—*F. vasinfectum* Atk. f.1 Wr.

Recently, Hansford, confronted with the difficulty of distinguishing *F. cubense* in culture from many other strains of the Elegans section of the genus, has concluded that the present classification of the section is useless and that the conception of a species of *Fusarium* must be broadened [*Proc. 9th West Indian Agric. Conf.*, 1924, pp. 43-44, 1925]. He considers that it is preferable to regard all the Elegans forms which he has encountered as strains of a single species. With this view, my own observations are in harmony and I now regard *F. udum* and the two forms discussed in the present paper as strains of the same species. Furthermore, *F. cubense* is so similar to the sesamum fungus that it can scarcely be considered as a distinct species, either on morphological or cultural characters. It appears to possess strains differing in their selective parasitism, *Musa cavendishii* being immune from it in the West Indies but susceptible in the Canaries. Finally, through *F. cubense*, which both Brandes and Wollenweber have noted to be scarcely different from *F. vasinfectum*, one is led to include the latter in the group of closely allied strains. In so doing I have reversed my previous opinion [*Rept. Agric. Res. Inst. and College, Pusa*, 1913-14, p. 54, 1914] which was based on cultural differences between the American and Indian cotton wilt fungi, these differences being now regarded as being too inconsistant to be used as satisfactory criteria.

Thus the wilt-producing fungi attacking cotton, sesamum and pigeon-pea in India may, in the writer's opinion, best be considered to be strains of *F. vasinfectum* Atk., which itself may be merely a strain of one of the earlier described species of the genus.

It appears as if Wollenweber has never been quite able to accept the view that *Fusarium udum* is synonymous with *F. vasinfectum*. In his most recent paper on the subject [Wollenweber, 1938] he has given a number of characters by which *Fusarium udum* may be distinguished from *Fusarium vasinfectum* Atk. and has listed also the distinguishing characters of *F. lateritium* var. *uncinatum* Wr., another species which is considered to cause a rather different disease. The researches described by the author have shown that both *F. lateritium* var. *uncinatum* and Butler's *F. udum* have hooked spores, both produce, in some isolates at least, salmon-coloured pionnotes, and on rice some isolates of both produce a yellow as well as an orange pigment. Formation of chlamydospores is a highly variable character, but *F. lateritium* var. *uncinatum*, as well as *F. udum*, can form both terminal and intercallary ones (Plate XLI). It is noteworthy that *F. lateritium* var. *uncinatum* is placed in the key by Wollenweber and Reinking [1935] in the group with microconidia normally present, whereas *F. lateritium* Nees belongs to the group with small conidia normally absent or one- to more-celled. This characteristic coupled with the type of chlamydospores produced places *F. lateritium* var. *uncinatum* in the section *Elegans*. Yet the hooked spores and the pigmentation admittedly resemble more closely those of the section *Lateritium*. Thus while the evidence appears overwhelming that *F. lateritium* var. *uncinatum* Wr. is a synonym of *F. udum* Butler, it is not a simple matter to decide whether or not the fungus should be regarded as a true member of the section *Elegans* or whether the dividing line between these two sections is made indistinguishable by this more or less intermediate form.

We may at this point consider the suggestion of Wollenweber [1913] that Butler's *Fusarium udum* is invalid and the proposal of the name *F. Butleri* for this species. As a footnote he wrote 'I propose the name *F. Butleri* for this species, because the name *F. udum* has already been used by Berkeley [1841] and refers to a distinct old species, well-known by its pionnotes stage covering the cut surface of oak, elm and other trees. It is also found on Irish potatoes, tulip bulbs and in the soil. It was temporarily transferred by

Saccardo [1886] to the genus *Pionnotes*, which, however, has no sound morphological basis [Appel and Wollenweber, Grundlagen..........1910].' Berkeley's fungus was named *Fusisporium udum*, not *Fusarium udum*. In 1886 this was changed by Saccardo to *Pionnotes uda* (Berk.) Sacc. Pionnotes was combined with *Fusarium* by Appel and Wollenweber only in 1910, after Butler had named *Fusarium udum*, though in the same year. Thus *Fusarium udum* (Berk.) Wr. is a non-valid homonym and on that account *Fusarium udum* Butl. cannot be rejected in favour of *F. Butleri*.

Next, is *F. udum* to be regarded as a distinct species, or is it to be merged with *F. vasinfectum* ? It is seen that the highly pathogenic isolates are rather distantly removed from *F. vasinfectum*. The only reason for merging *F. udum* and *F. vasinfectum* would be that a complete range of intermediate forms existed. Although the cultures vary considerably, there is no evidence at present to suggest that such a complete range could be demonstrated. A thorough comparison has been made of typical variants of *F. udum*, with all varieties and forms of *F. vasinfectum*. In colour and spore form they comprise a group which, though variable, does not appear at its extreme limits to overlap *F. udum*, either as regards the hooked conidia or the pigments produced. For the time being, at any rate, the two species should be regarded as distinct.

The significance of these conclusions may be considered in relation to the pathological aspect. Butler in 1910 described *F. udum* in its narrower sense, and as late as 1918 he held the view that this fungus was restricted to pigeon-pea as a host. In 1926 he merged the species with *F. vasinfectum*. He may not have realised it at the time, but he was to a large extent widening the conception of *F. vasinfectum*, not only to include a different species, but perhaps to include a species which might even not belong to the section *Elegans* at all. Possibly other workers at the same time also had a wide conception of the species *F. udum*. Particularly is this true of the work of Small. In 1925 Small crystallised his ideas on this fungus, and decided that its pathogenicity depends less on the strain of the fungus and the presence of a possible host plant than on the environmental conditions under which the fungus comes into contact with its host. With regard to the cultural characters of the fungus he says 'emphasis may be laid on the constant nature and dirty- or creamy-yellow colour of the pionnotes.' Finally, of its taxonomic position he concludes 'The *F. udum* of these notes is also distinct from *F. udum* (Berk.) Wr. and from Sherbakoff's variety *solani* of the species, and while it resembles *F. striatum* in many points, particularly in the typical presence of pseudo-pionnotes, it remains nearer to *F. radicicola*.' *F. radicicola* is now regarded by Wollenweber and Reinking [1935] as a variety of *F. javanicum*, which is a member of the section *Martiella*, having spores with much thicker and more durable cell walls and septations than those of the members of the section *Elegans*. The colours of the fungus and of its spore-masses, judged by the rather meagre description given by Small, do not resemble the colours typical of *F. udum*. *F. javanicum* var. *radicicola* is a cause of potato tuber-rotting in America, and Small found his fungus to be so in Uganda. Experiments conducted at the Imperial Agricultural Research Institute have failed to demonstrate that *F. udum* can cause rotting

of tubers. On the whole, it seems probable that Small was working with a fungus or fungi distinct from Butler's *F. udum* and more closely related to culture F 169 of this work, which may be a member of the section Martiella.

At present it is not clear whether Wollenweber's isolate of *F. udum* differs from those obtained by the author in respect of its pathogenicity. Wollenweber describes the fungus as a foot-rot organism. The author's isolates produce a true wilt, but in the plants which are killed in the seedling stage a considerable amount of rotting of the cortex also occurs. It may be noted that the first occurrence of 'wilt' in Wollenweber's experiments was when the plants were nine weeks old. This is certainly not typical of a foot-rot disease as understood in the *Fusarium* foot-rots of other crops, which usually show the symptoms in the very young stages. Butler [1910], describing his culture solution experiments, found that in the roots above the level of the solution the fungus 'led to browning of the cortical cells, visible externally as a distinct brown mark at the point of inoculation'. His figure (Plate II, fig. 1) certainly suggests that although the fungus is primarily a vascular invader it is capable also of rotting the roots. The point can only be settled by inoculation experiments.

It is proposed to call the wilt organism of *Cajanus cajan* '*Fusarium udum* Butl. var. *cajani*' and that of *Crotalaria juncea* '*Fusarium udum* Butl. var. *crotalariae*.'

Summary

(1) This paper deals with the identity of a number of isolates of *Fusarium*. capable of causing wilt of cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*).

(2) The fungi were grown on 2 per cent potato dextrose agar, Brown's agar, Brown's starch agar and steamed rice, and compared for all important cultural characteristics.

(3) The cultures which cause typical wilt of high percentages of pigeon-pea and sunn-hemp were found to differ from *Fusarium vasinfectum* Atk. in three major characteristics, namely, that they produced abundant spores in pionnotes, these spores usually tended to be strongly hooked at the apex, and bright orange and yellow colours were produced on steamed rice, whereas *F. vasinfectum* produced few or no pionnotes, the spores although curved were not hooked, and the predominant colour on steamed rice was a red hue which changed to deep purple on addition of 2 per cent potassium hydroxide solution.

(4) Several cultures causing wilt of sunn-hemp produced spores much broader than those of *F. vasinfectum* or the typical pigeon-pea and sunn-hemp organisms, and they probably belong to the section Martiella.

(5) The typical pigeon-pea and sunn-hemp wilt organisms, although sharply differentiated on a parasitic basis, are indistinguishable from one another morphologically and culturally, and are in fact *Fusarium udum* Butl., a highly variable species particularly with regard to ability to form chlamydospores, and as regards length of spores and range of colours produced.

(6) A number of isolates of *F. udum* were compared with *F. lateritium* var. *uncinatum* Wr. and also with cultures of all varieties and physiologic

forms of *F. vasinfectum*, obtained from the Centraalbureau voor Schimmelcultures, Baarn. This experiment strikingly confirmed the previous conclusion that *F. udum* is a separate species from *F. vasinfectum*. It proved that *F. lateritium* var. *uncinatum* is a synonym of the earlier species *F. udum*, and that it produces terminal as well as intercallary chlamydospores.

(7) The names *F. udum* Butl. var. *cajani* and *F. udum* Butl. var. *crotalariae* are proposed for the wilt organisms of *Cajanus cajan* and *Crotalaria juncea* respectively.

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Note

After the Ms. was submitted for publication, I received a paper entitled 'The species concept in *Fusarium*' (Synder, W. C. and Hansen, H. N. 1940. *Amer. J. Bot.* **27**, 64-67). All of species *Fusarium* in the section *Elegans*, including *F. udum* Butl., are formally made physiologic forms of *F. oxysporum* Schl. The changes are based on 'the general nature of, and variability in, *Fusaria*', resulting from a study of a few of the species and varieties, and details of the evidence for the changes are not given. It has been clearly shown in the work described above that *F. udum* Butl. stands as a good species despite generalized remarks to the contrary. The significance and validity of the changes proposed, especially as they bear on the conclusions reached in Part III of this series of papers (*Ind. J. Agric. Sci.* **10**, 241-84: 1940), will be the subject of further remarks.

INVESTIGATIONS ON *SPATHIUS CRITOLAUS* NIXON, AN IMPORTANT BRACONID PARASITE OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST. OF SOUTH INDIA

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(With Plates XLII and XLIII and two text-figures)

INTRODUCTION

SPATHIUS CRITOLAUS Nixon is an indigenous primary ectophagous parasite on the grubs of the cotton-stem weevil, *Pempheres affinis*, in South India. It invariably attacks host-grubs in an advanced stage of growth. Normally the egg, larval and pupal stages of the parasite are all passed within the tunnel bored by the weevil-grub in the stem. The first record of this Braconid in association with this pest was by Ramakrishna Ayyar and Margabandhu [1936]. Beyond the mere record nothing was known regarding its biology, habits or host relations. A knowledge of these aspects is necessary not merely because of the possible utilization of the parasite in the control of the stem weevil but also because the biology of no member of the genus *Spathius* appears to have been studied in detail from South India. This study has been in progress for a period of over two years. The writer has been greatly assisted in this work, particularly in the routine part thereof, by Assistant Mr. P. S. Narayanaswami, and Fieldman Mr N. Muthuswami, the latter having been specially helpful in the collation of data and preparation of the tables.

THE HOST

Pempheres affinis has been known in India for over 25 years. It is by far the worst pest of cotton wherever it occurs in South India, causing a loss of about 30 per cent or more in the case of severe outbreaks. The injury inflicted is by the extensive tunnelling of the stem by the immature stages. This weevil under field conditions passes through nearly three successive generations during the cotton season, October to March, though considerable overlapping of generations occurs even at the beginning of the second brood. From a small population of a few immigrants to cotton fields in the initial stages of the crop, huge populations are built up as the season advances. The weevil appears to be an indigenous pest from all available evidence. Its original source appears to be from wild food plants of the genera, *Triumfetta*, *Sida* and *Hibiscus* scattered in hills and plains. Only five species of the genus *Pempheres* are known so far, all being confined to the Indo-Malayan region. In South India it has no effective natural enemy in the field.

ADULT PARASITE (PLATE XLII, FIGS. 1, 2, 3)

The parasite has been recently identified as a new species and described under the name *Spathius critolaus* [Nixon, 1939]. It is a slender, elongate, reddish-brown insect with a dark abdomen and vestigial wings, having a strong resemblance to *Cremastogaster* ants. The males are generally smaller and narrower than females. The length of ovipositor is often variable. Occasionally winged forms appear in both the sexes but winged males are rare and have been obtained only in one instance. Winged females are much commoner both in collections and rearings and make an appreciable proportion of the total females. The sizes of the adults vary within a wide range largely depending on the nutrition afforded during development by the host. The measurements of a large number collected from nature as well as those bred in the laboratory have been taken. The figures recorded do not include antennae and ovipositor.

Female.—Length ranges between 2·53 mm. and 3·25 mm. averaging 3·05 mm. Width at the widest part of the abdomen varies from 0·70 mm. to 0·85 mm. averaging 0·78 mm.

Male.—Length varies from 2·1 mm. to 3·12 mm. averaging 2·625 mm. Width varies from 0·67 to 0·75 mm. averaging 0·713 mm.

TECHNIQUE

Being a larval parasite of a stem borer the study of the parasite is particularly arduous and difficult. *Pempheres* larvae are also perhaps the most difficult to rear under artificial conditions. Suitable stages of the pest were obtained by careful dissection of plants from the field and active non-parasitised healthy stages were selected for oviposition trials. Three to four grubs were introduced into small cells scooped out in a fresh cotton stem providing a thin door-like covering of the bark. The host-grubs were placed in position each inside a cell and covered by the lid of bark and the whole thing fastened by thin cotton threads. The stems were kept fresh and green by keeping them in culture solution provided in small tubes. The stem with the tube was placed in a cylindrical wire-gauze or glass cage with its open end protected by muslin covering. A pair of adult parasites was introduced into the cage and food in the shape of sugar or honey solution was supplied in a bit of sponge suspended from the stem. Later, raisins were substituted and were found to be more convenient. Every day these stems were removed and examined under a binocular for eggs and fresh stems with hosts supplied. For oviposition studies on a large scale, a pair of parasites or a mated female with a daily supply of fresh loaded stem and raisin were put inside long tubes (6 in.$\times$1 in.). After ovipositon the host with egg was either transferred into small paraffin cells made by sinking a heated nail head and covered with a cover glass or into small gelatin capsules. In order to gather accurate data on the percentage parasitism in nature, daily or weekly collections of plants were individually dissected and examined for noting the parasite stages.

GEOGRAPHICAL DISTRIBUTION

A thorough study of its distribution has not been possible. The parasite has been observed and collected from Coimbatore and its environs, Erode

and surrounding villages, Ramnad and Malabar districts. From Malabar the parasite has been obtained from plant hosts other than cotton, such as *Triumfetta* and *Sida*. As a result of observations so far made, it may be assumed that the parasite is distributed throughout localities where the pest exists in any large numbers. It has also recently been recorded [Nixon, 1939] as being bred from seeds of *Prosopis spicigera* by S. D. Bhatt in the Punjab. In the latter place, the macropterous forms of males seem to be more predominant than macropterous females which is just the reverse of what occurs in South India.

Host range

The host preferences of the parasite seem to be somewhat restricted. In nature the parasite has been recovered from three distinct hosts, all being stem-borers, two of which are Curculionid grubs and the third a Bostrychid. It has been seen to parasitise *Pempheres* not only in cotton but also in various alternate host plants such as *Triumfetta rhomboidea*, *Sida acuta*, *Corchorus olitorius*, *Hibiscus esculentus*, *H. vitifolius*, *H. ficulneus*, and *Malvastrum coromandelianum*. Another insect which is found parasitised in nature, though infrequently, is the common weevil-borer grub of amaranthus (*Hypolixus truncatulus*). A third important alternate host is the Bostrychid borer (*Sinoxylon sudanicum* Lesne) infesting Cambodia cotton stalks. This Bostrychid attacks occasionally even green healthy plants in the field but prefers wilting plants in the field as also those collected and stored in the open. This phenomenon has been taken advantage of in the matter of mass-breeding of the parasite by manipulation of the host in large out-door cages.

Mating

Mating may occur immediately on emergence in a manner typical of most Braconids. The male appears to be particularly ready for copulation on issuing out of the cocoon even before feeding. In a small proportion of cases the sexes appeared to be indifferent to each other for a few minutes on coming out of the cocoon, especially when these were located at a distance in the same tube. The male apparently fails to recognise the female at a distance of nearly 5 or 6 in., but when they come near enough commence to show signs of excitement. Several copulating pairs have been watched in the cages and the duration of coupling has not exceeded 40 seconds but averaged about 20 to 25 seconds after which the female slips away. Very rarely have the males been noted to be able to effect a second copulation within a short interval. The same males however have been utilized to serve two to three females successfully at short intervals. Exposure to sunlight does not seem to make any difference in their behaviour except that they try to move away from the bright side.

Pre-oviposition period

The duration of time between emergence and egg-laying varied within a wide range in the species. This duration is probably governed by numerous factors such as mating, temperature and humidity, nature of food supplied

and also by the nature of the host provided. This period has been accurately recorded for about 63 individuals including 12 winged fertilized females and 10 virgin apterous females. In mated wingless females, the period ranges from 2 to 16 days averaging seven days for 41 cases. In mated winged forms, this period ranged from 2 to 28 days averaging 9·3 days for 12 cases. In the case of unmated females, the period ranged from 2 to 16 days averaging 10·2 days for ten virgins. In order to see the number and nature of the development of the egg, a few females were dissected under a binocular during the pre-oviposition period. On an average three to five developed eggs and as many partly developed ones were observed.

Oviposition

The preliminary search and manœuvres and the actual process of oviposition have been carefully watched in a number of cases in cages. Mating is not essential for oviposition. At first the female wanders over the stem or sides of cages or it may stop and rest quietly in any part of the cage without any sign of activity. Sometimes a spot is thoroughly inspected and the ovipositor inserted into and withdrawn from an artificial cleft as if feeling for the concealed grub. Often a spot apparently chosen was afterwards rejected. Not infrequently the female returns to the same spot after short wanderings and commences to evince a lively interest.

Process of oviposition.—After locating a spot containing an active host, it takes a firm stand, raises the abdomen and directs the tip of ovipositor forwards and commences a search with the tip. Perhaps the position of the host is discovered by touch through the agency of the ovipositor sheath. The antennae are either extended forwards or held diverged sideways. Very rarely they were directed downwards. The stylets of the ovipositor are slowly released and projected out with the two valves of the sheath yielding and forming a loop curving backwards. The stylets are slowly thrust deeper and deeper through the bark where it is weak, the loop formed all the while becoming wider and wider. Some times these are withdrawn fully or partially and two or three thrusts are quickly made in the same puncture. The stylets in a great majority of cases remained inserted for several minutes. The parasite has apparently stung the host and an egg is found laid soon after. After this operation, the ovipositor is withdrawn and sheathed and the parasite moves away from the spot. Sometimes all these operations were carried out resulting merely in the paralysation of the host, without the actual deposition of an egg. Very often artificial slits found in the stem are taken advantage of for insertion of ovipositor. The time taken for the process varied within a wide range. In the majority of cases the time taken varied between ten and 30 minutes. The maximum duration observed was about 90 minutes.

Time of oviposition.—Oviposition can take place probably during all hours of the day and night but more during night. Generally oviposition has been a common feature in cases where stems with host-grubs were supplied at 5 P.M. and removed at 9 A.M. the following day. On the other hand stems supplied at 9 A.M. and removed at 5 P.M. the same day did not give many egg-layings. Oviposition is more vigorous and regular in the earlier stage than in the later stage of the life of the female.

TABLE I

Oviposition record during 1936-37

Serial No.	Egg-laying period	Total eggs laid	Total longevity	Post-oviposition period
Mated females (wingless)				
1	41	43	51	4
2	53	33	61	5
3	43	38	50	5
4	19	19	51	31
5	49	20	63	12
6	19	16	60	37
7	22	21	45	14
8	22	32	33	4
9	42	44	60	4
10	12	20	46	13
11	35	47	47	2
12	57	41	71	3
13	66	23	84	8
14	29	26	84	54
15	51	31	59	4
16	56	25	72	17
17	39	17	68	20
18	29	27	45	18
19	19	22	46	?
20	29	22	66	32
21	37	22	63	21
22	37	36	44	3
23	52	21	66	10
24	20	22	41	13
25	29	20	57	21
26	41	14	88	40
27	29	16	47	14
28	39	10	74	29
29	39	10	74	29
30	75	29	94	11
31	39	22	47	2
32	39	25	107	47
33	55	15	65	8
34	37	20	62	15
35	31	13	71	32
Mated females (winged)				
1	15	11	39	38
2	56	53	64	7
3	16	13	34	8
4	25	24	62	33
5	13	8	51	25
6	71	22	109	23
7	24	16	57	5
8	30	25	48	6

TABLE I—*contd.*

Serial No.	Egg-laying period	Total eggs laid	Total longevity	Post-oviposition period
		Virgin females		
1	38	33	56	2
2	30	26	46	?
3	33	19	39	4
4	11	10	32	14
5	59	30	124	19
6	25	12	37	1
7	56	38	70	9
8	28	15	65	23

Method of locating the host.—A few experiments conducted in cages go to show that antennae are not probably very helpful in the process of oviposition. It is known that many species of parasites locate the host by search through the olfactory sense located in the antennae. A set of three experiments was conducted with mated ovipositing females after the complete removal of antennae leaving only minute stumps. Such females were not very steady in their gait and showed a slight change in their behaviour. One of these laid four eggs and the others six each subsequent to the removal of the antennae. The experiments are too few to be conclusive but it looks as if their efficiency is thereby considerably lessened and the egg-laying capacity diminished.

Position and number of eggs per host.—The number of eggs laid by a female per day was never large. It was commonly one, two or three and the maximum five. The eggs are laid indiscriminately on any part of the host. These may be placed crosswise or lengthwise without any attachment and these may be easily detached by slightest shock. Sometimes the eggs are found loosely lying in the host tunnel amidst excreta and frass. In the matter of laying only one egg per host it may be considered to be very economical and not wasteful because within its limited egg-laying capacity it can destroy a large number of hosts.

Egg-laying period and individual egg capacity.—In the case of mated wingless females the length of oviposition period ranged between 12 days and 66 days and averaged 38 days for 35 individuals (Table I). In the case of winged forms (also mated) the range was between 13 days and 71 days averaging 31·1 days for eight cases. Virgins showed a variation from 11 days to 59 days averaging 35 days for eight cases.

The same table furnishes records of the total number of eggs laid by a lot of 51 individuals. The maximum number noted for a female was 53 eggs. The egg-laying capacity for mated wingless forms varied from 13 to 47 eggs averaging 38 eggs for 35 cases. Mated winged forms showed a range from 8 to 53 eggs averaging 21·5 eggs for eight cases. Whereas virgins showed a range from 10 to 38 with an average of 23 eggs for eight cases, the virgins

evidently show a diminished egg-laying capacity. The post oviposition period is considerably prolonged in some cases and reaches a maximum of 54 days with a minimum of two days averaging 15·8 days for 49 individuals.

Selection of host stages.—The female always chooses an active host-grub and stings and paralyses it before oviposition. It seldom oviposits on grubs already paralysed by other insects or rendered inactive by other causes. It occasionally oviposits on host-grubs already paralysed by members of the same species. The females could not be induced to oviposit on other stages of *Pempheres*, *Sinoxylon* or *Hypolixus* such as prepupae, pupae, etc. Grubs boring deep into the centre of thick woody stems were rarely attacked being nearly inaccessible.

Effect upon the host and its survival.—The extent of paralysis of the host no doubt may vary according to circumstances. Usually the host-grub is rendered inert and dull. It becomes limp, relaxed and flaccid. It seldom moves though not dead. It does not feed and no peristaltic action is seen except when disturbed. In a few cases the heart beat, though feeble, was perceptible for some time. Such larvae showed one or more dark brown marks on the cuticle. These marks are really the scars produced by the sting or thrusts of the ovipositor. Some experiments have been conducted to test whether such grubs survive after freeing them of the eggs. These were never seen to revive, but continued, when kept in stems, to be fresh without decay or discoloration for a maximum period of about 15 days. They never survived but died a slow death after a period when they got dried up in the case of *Pempheres* and *Sinoxylon* grubs. It shows that such paralysis is eventually fatal in the case of these host-grubs. It is not a mere paralysis of the nerve centre since the sting marks have been found to be located on any part of the host-grub. The paralysis serves the admirable purpose of keeping the tissue of the host-grub fresh and in good condition for the newly hatched larva. The case of large-sized *Hypolixus* grubs is slightly different. In many cases the paralysis was only partial. Such larvae seemed to move and roll over slowly, wriggle or squirm to some extent apparently with a view to dislodge the egg or larvae. Even these grubs succumb soon after the egg hatches and the larva begins feeding.

Immature stages

Egg (*Plate XLIII, fig. 1*).—The eggs do not vary much in size generally but under-sized females have been seen to lay eggs of smaller size. The egg is barely visible to the naked eye. Maximum length 0·78 mm., minimum length 0·566 mm., average length 0·66 mm. Maximum width 0·15 mm., minimum width 0·10 mm., and average width 0·13 mm. for 35 eggs. The freshly laid egg is somewhat cigar-shaped and distinctly arched with the two poles unequal and rounded. The cephalic end is wider and more broadly rounded, being nearly one-and-a-half times as broad as the caudal end. Occasionally the shape departs a little from the normal in having a bulb-like expansion near the caudal end. This may be probably due to the uneven pressure at the time of deposition.

When freshly laid the egg is shining translucent white except at the caudal extremity which is glassy and transparent. The chorion is thin and smooth with no apparent sculpturing.

The time taken for hatching varies from one to two days averaging 1·4 days for 50 observed cases. It varies according to season and temperature within the range indicated.

Larva

I stage larva (*Plate XLIII, fig. 2*).—The newly hatched larva is a clear white delicate creature almost transparent. It is very nearly cylindrical with a slightly flattened head and 13 well-delineated body segments. The integument is apparently naked and unarmed without any spines, setæ or pigmentation but under the microscope presents a rough sculptured surface with setæ-like minute elevations. The head is slightly more chitinised than body segments though concolorous. Under a binocular a slightly dull pouch-like stomach is visible in the middle. The labrum is distinct and ventral and under a binocular the fleshy mouth-parts and sharp mandibles (Plate XLIII, fig. 3) are clearly seen. The tracheal apparatus is only imperfectly visible at this stage. The mandibles are somewhat triangular with a pointed sharp little tooth the lower curved border of which is provided with a pair of fine denticles.

Dimensions : Length varies between 0·62 mm. and 0·8 mm. averaging 0·68 mm. for 16 specimens measured. Width varies between 0·13 mm. and 0·175 mm. averaging 0·15 mm. Width of head varies from 0·1 mm. to 0·125 mm. averaging 0·11 mm.

On leaving the egg-shell, the larva crawls on the body of the host for a short distance and fixes its head on the host and commences to feed. Very often the eggs are found fallen off and detached in the tunnel and these hatch at a distance from the host. These tender larvæ crawl aimlessly by using the abdominal tip and mouth-parts for locomotion. The movement is comparatively rapid for its size. It attaches itself to the host if it comes across one in its journey. Otherwise it stops motionless, contracts and eventually dies. The larvæ do not linger much on the dorsal or exposed surface but generally crawl to lateral or ventral side of the host. In a few hours the larva gets swollen by feeding and the stomach contents show prominently with a yellowish tint.

II stage larva.—In general form it is similar to the previous stage but chiefly differs in colour and size. It is now less transparent. The shape is still cylindrical but the head is more globular. It is a little thicker in the middle and displays slight traces of the beginnings of urate cells. The cuticle possesses a fine covering of small setæ. The larva is widest between abdominal segments 1 and 3. Length varies from 1·05 mm. to 1·55 mm. averaging 1·21 mm. for 15 specimens. Width varies from 0·30 mm. to 0·35 mm. averaging 0·33 mm. Width of head varies from 0·15 mm. to 0·175 mm. averaging 0·33 mm.

III stage larva.—In this stage the larva is slightly arched becoming thicker in the middle with tapering extremities. Arched segmental convexities are visible and are larger in the first four abdominal segments which contract and dilate probably to help the larva in locomotions. The head is also comparatively larger and well differentiated. It is yellowish in colour. The white urate cells distributed on the sides and extending dorsally are more conspicuous and stand out distinctly. The trachæ are more ramified. The cuticular setæ

SPATHIUS CRITOLAUS NIXON

FIG. 1. Micropterous female (×13)

FIG. 3. Micropterous male (×12½)

FIG. 2. Macropterous female (×13)

FIG. 1. Egg (×200)

FIG. 2.
1st stage larva (×42)

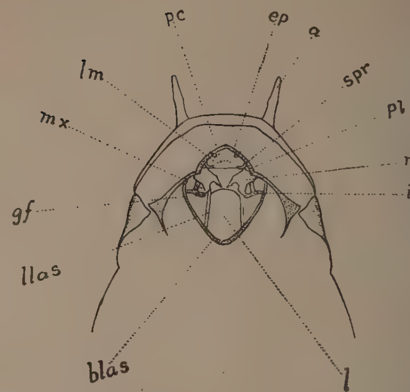

FIG. 3. Mouth-parts of 1st stage larva

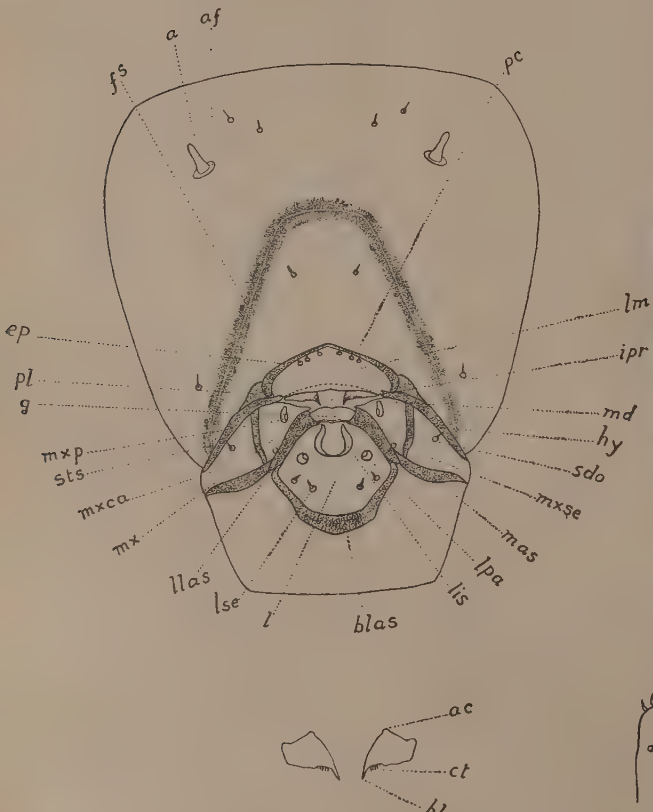

FIG. 5. Head and mouth-parts of full-grown larva (ventral view)

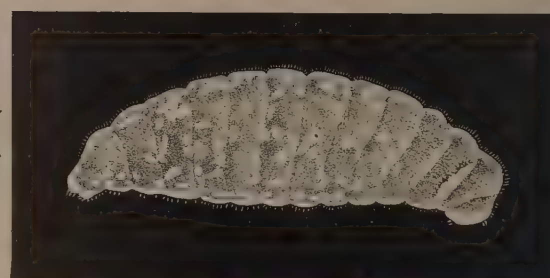

FIG. 4. Full-grown larva showing urate granules (×18)

FIG. 6. V and VI segments of full-grown larva showing setal disposition (dorsal view)

[a=antenna; af=antennal foramen; ac=mandibular acron; blas=basal labio-stipital sclerome; mxca=maxillary cardo; ep=epistoma; fs=frontal suture; gf=glenoid fossa; hy=hypostoma; ipr=inferior pleurostomal ramus; l=ligular region; llas=lateral labio-stipital sclerome; lis=ligular sclerome; lm=labrum; lpa=labial palpus; l se=labial seta; mas=maxillary sclerome; md=mandible; mx=maxilla; mxp=maxillary palpus; mx se=maxillary seta; pc—preoral cavity; pl—pleurostoma; sdo—silk duct orifice; st s—stipital sclerome.

MANDIBLE

bl=blade; ac=acron; ct=comb-like teeth (denticles)]

appear more prominent when viewed under a binocular. Two dorsal rows of longer hairs are seen one on either side of median line. Length ranges from 1·6 mm. to 2·35 mm. averaging 2·17 mm. for ten specimens. Width ranges from 0·5 mm. to 0·725 mm. averaging 0·615 mm. for ten cases. Width of head ranges from 0·25 mm. to 0·275 mm. averaging 0·255 mm.

IV and final stage larva.—Size is very variable (Plate XLIII, fig. 4) depending on various factors particularly nourishment. Length 2·725 mm. to 4·32 mm. averaging 3·3 mm. for 13 individuals. Width 0·9 mm. to 1·45 mm. averaging 0·35 mm. Width of head 0·30 mm. to 0·45 mm. averaging 0·35 mm. Length of antennæ varies from 0·02 mm. to 0·025 mm. averaging 0·022 mm. for nine cases. In general shape, this and the previous stage are more or less similar. It is crescent shaped in its lateral aspect and is typically hymenopterous in form with a distinct head followed by 13 segments. It is widest in the middle tapering bluntly towards extremities. The general colour is still yellowish with a dirty brownish yellow mid-intestine. The granular urate cells show themselves more prominently. The segmental transverse lobes are more pronounced imparting a slightly flattened appearance. The body has a smooth appearance but under a binocular appears to be closely set with numerous minute setæ or spines.

Head.—In rough outline it has the appearance of a truncated heart with a sort of chin below. The truncated cone-like antennæ are larger and are placed on cuticular disc-like elevations. The integument is more chitinised and hard than in the early stages. The buccal organs (Plate XLIII, fig. 5) are visible and well defined. The upper lip is a thin semi-circular membrane partially covering the mandibles. The mandibles are more heavily chitinised, larger and sharper. They are disposed horizontally and are directed inwards and downwards. These bear five small comb-like denticles on the posterior edge; the maxillæ are membranous having a pair of maxillary palps. The labium is transparent bearing sensorial setæ. The salivary duct opens at the apex of the labium.

Body.—Body consists of 13 segments. Each segment has a number of fine, short setæ with a median long hair three or four times as long as the setæ (Plate XLIII, fig. 6). These hairs are so arranged as to form a dorsal median longitudinal row among the tegumentary setæ. The nine spiracles are clear and are located in slight depressions near the anterior border of the corresponding segment. The respiratory system as usual is made up of two longitudinal trunks connected anteriorly and posteriorly by transverse commissures. Each lateral trunk is connected to the spiracles by spiracular branches. At the root of each spiracular branch there are fine branches proceeding both dorsally and ventrally. These are seen to ramify extensively.

Larval development.—The parasites fail to develop when they are transferred while young to a non-paralysed healthy grub with mangled mouth-parts. Such hosts soon get diseased, darkened or fungus attacked. On transferring a parasite larva from one paralysed grub to another, normal development followed. Normal development does not take place when host-grubs killed in hot water are substituted. The entire question of development is governed not only by the quantity of food afforded but also quality and a paralysed larva constitutes the best medium.

Cocoon

The full-grown larva stops feeding, leaves the host remains and in about 24 hours starts spinning a cocoon about itself in the same tunnel in some suitable spot. This silken cocoon is perfectly white in colour. It is more or less uniform forming a complete parchment-like covering for the larva. The shape is not always uniform in cages. It is generally cylindrical and tubular in outline in nature but may be slightly short or loose or rhomboid in cages. When disturbed at this stage, the larva may enter into prepupal and pupal stage outside such cocoons or fail to develop further. In paraffin cells and gelatin capsules the cocoon was usually much thinner and sparsely lined with threads. In a small percentage of such cases no cocoon worth the name was spun and pupation occurred naked. Larvæ confined in tubes and flat surfaces on depression slides very often did not spin any cocoon except having a few loose threads thrown out irregularly. Apparently the walls of the tunnel, bark or any rough surface are required for scaffolding. The time taken to complete the covering averaged between 10 and 15 hours in a dozen cases noted. In about six hours a thin covering is more or less completed and the larva is barely visible through the cocoon. The female cocoons were slightly larger than those of males. Average length and width of 33 female cocoons were 5·5 mm. and 1·6 mm. The average length and width of male cocoons were 4·7 mm. and 1·5 mm.

Prepupa

Shortly after the completion of the cocoon the larva enters into the prepupal stage, having cast off the meconium in the shape of a brownish-dark mass at the posterior end of the cocoon. The larva does not undergo any material change except that it is motionless and slightly shrunken in size save at the thoracic portion.

Pupa

Just prior to pupation the last larval cuticle splits and is slipped off to the posterior end of the cocoon. The pupa at this stage is creamy white with even the eyes white. In a day the pigment appears first on pronotum and head. In another two days the eyes turn pinkish. The appendages are held loosely attached to the body. The pupa soon turns slightly yellow, becomes brown in another day and acquires the outline of the adult segments as also its colour and shape.

Emergence of the adult

When the pupa reaches maturity the fully formed adult becomes active and movements of head, antennæ and front legs may be seen. A small irregularly circular aperture is eaten at the anterior end of the cocoon a little on the dorsal or lateral aspect and the adult emerges out of the cocoon into the host tunnel. After gnawing a small rounded aperture through the bark or stem the adult makes its final exit into the outside world.

Life-cycle

The data on life-cycle periods were obtained from individual rearings from egg to adult in paraffin vials, gelatin capsules or in cells hollowed out in small bits of cotton stems confined in tubes. Life-cycle periods have been thus recorded for over 200 adults during 1936-37. Table II presents complete data for several stadia in relation to sex and host.

TABLE II

Parasite stage	Duration of range in days	Average in days	No. of cases
Egg period	1-2	1·2	26
Larval period, females	3-8	4·77	13
Larval period, males	3-7	4·64	11
Pre-pupal period, females	1-3	2·3	9
Pre-pupal period, males	1-3	2·75	4
Pupal period, females	5-13	8·6	12
Pupal period, males	5-10	7·5	4
Total period of females from egg to adult during April to December 1936 on *Pempheres*	12-19	16·0	37
Total period of males from egg to adult during April to December 1936 on *Pempheres*	11-20	14·3	51
Total period of females from egg to adult during April to December 1936 on *Hypolixus*	17-27	19·9	46
Total period of males from egg to adult during April to December 1936 on *Hypolixus*	13-28	18·7	35

TABLE III

Data on life cycle periods on the host Sinoxylon sudanicum *during the months July to September 1936*

Parasite stage	Duration of range in days	Average in days	No. of cases
Egg period	1-2	1·3	6
Larval period	4	4·0	5
Prepupal period	1-2	1·8	5
Pupal period	7-10	8·4	5
Total life-cycle from egg to adult, females	13-18	17·2	15
Total life-cycle from egg to adult, males	14-18	17·0	45

The total life-cycle duration showed slight variation during the three different months.

The parasite has also been successfully reared on another host, i.e. on mature grubs of pulse bruchids, *Bruchus theobromæ* L. The rearing technique was the same as in other hosts. The total life-cycle period from egg to adult in June-July 1936 occupied about 18 days for both the sexes.

Seasonal variations in life-cycle periods.—For about 270 parasites consisting of males and females reared individually on different hosts during the period 1936-37, the life-cycle periods have been carefully recorded. The figures represent the averages of life-cycle periods worked out for several males and females during all the weeks of the month.

TABLE IV

Seasonal variation in life-cycle duration, in days, on different hosts for males and females, 1936-37

Month	1936						1937	
	Pempheres		*Hypolixus*		*Sinoxylon*		*Hypolixus*	
	Females	Males	Females	Males	Females	Males	Females	Males
	days	days	days	days	days	days	days	days
April	13·1	13·0	..	13·0	..	..	13·4	13·6
May	14·4	13·8	16·2	..	..	..	15·2	14·6
June	17·8	14·2	20·0	..	..	..	18·0	18·5
July	16·5	16·7	19·0	16·6	16·7	15·9	19·5	19·5
August	..	..	..	..	18·0	18·0	16·2	18·3
September	..	..	18·6	16·0	17·0	17·0	20·8	17·5
October	..	..	19·6	18·0	..	..	18·7	17·5
November	18·0	16·0	20·9	19·2	..	..	19·0	20·5
December	..	..	22·0	20·0	..	..	19·0	27·0

The records of rearings on *Hypolixus* in the year 1937 show that the males have a slightly longer life-cycle period than the females.

Effect of climatic factors on the life-cycle.—For the years 1936, 1937 and part of 1938, the mean temperatures and humidities have been presented in a graphical form in Figs. 1 and 2. The months of March, April and part of May happen to be hottest periods of the year when the temperature is at the highest (mean 89·5°F.) with a low mean humidity of 52·7 per cent to 56 per cent. The development of the parasite is seen to be the quickest at this period with the shortest duration in the egg, larval and pupal stages. The life-cycle period reaches a minimum of 11 days with a maximum of 14 days in April averaging 13·5 days for about a dozen individuals reared. With the advent of monsoon in the latter part of May though the temperature is still high there is a rise in humidity to some extent. The duration of life-cycle ranges between 13 and 16 days averaging about 14·9 days for 19 individuals reared during the month. In June there occurs a sudden fall in temperature from 89·5 to 82·0 with a rise in humidity from 56·9 to 66·3 per cent and the life-cycle period ranges from 16 to 20 days averaging 18 days. From July to November there is a gradual fall in temperature with an increase in humidity. The

former drops down to 77°-78° F. and the latter rises to 73 per cent in November with slight fluctuations. The life-cycle, therefore, gets prolonged from about 15 days in May to about 24 days and 27 days in November-December. There are slight fluctuations in the weather conditions during the months, such as a warm spell or heavy rains and these are more or less reflected in the slight reduction or prolongation of the duration of the life-cycle from 17 to 27 days as may be seen from Table IV. Leaving out the exceptional increase in humidity to 73·3 per cent in November, it may be noted that the variations in humidity during the months of June to December are found within the brief limits of 65 per cent to 68 per cent, whereas the deviations in temperature are slightly more pronounced as is manifested by the fall from 82° to nearly 77° F. It may be inferred, therefore, that the temperature perhaps is the more dominant of the factors in controlling the duration of the stages although the humidity factor is seen to exert its influence by either accentuating the former's effect by a decrease or considerably diminishing the same by a sharp rise. The data recorded from the rearings in 1937 confirm the above observations. During the cooler months the incubation is prolonged from one to two days, the larval period from three to eight days, the prepupal period from one to three days and the pupal period from 5 to 13 days. Excess of humidity manifests itself in an increase in fungus diseases or in the rapid multiplication of the predaceous laboratory mite *Pediculoides ventricosus* Newpt. This mite has been a constant menace in the laboratory in spite of all precautions.

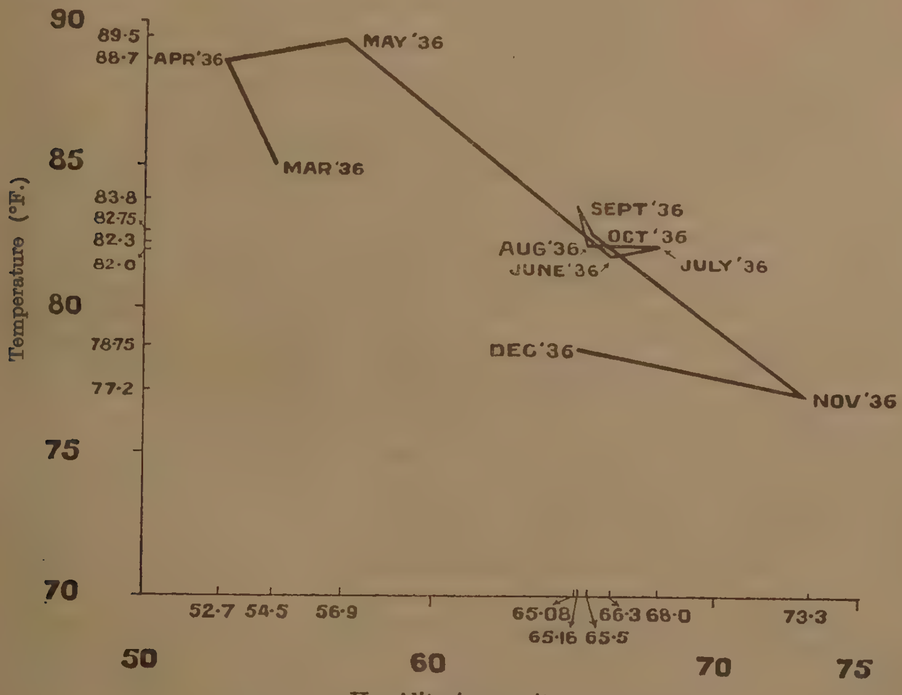

FIG. 1. Temperature-humidity, curve, 1936

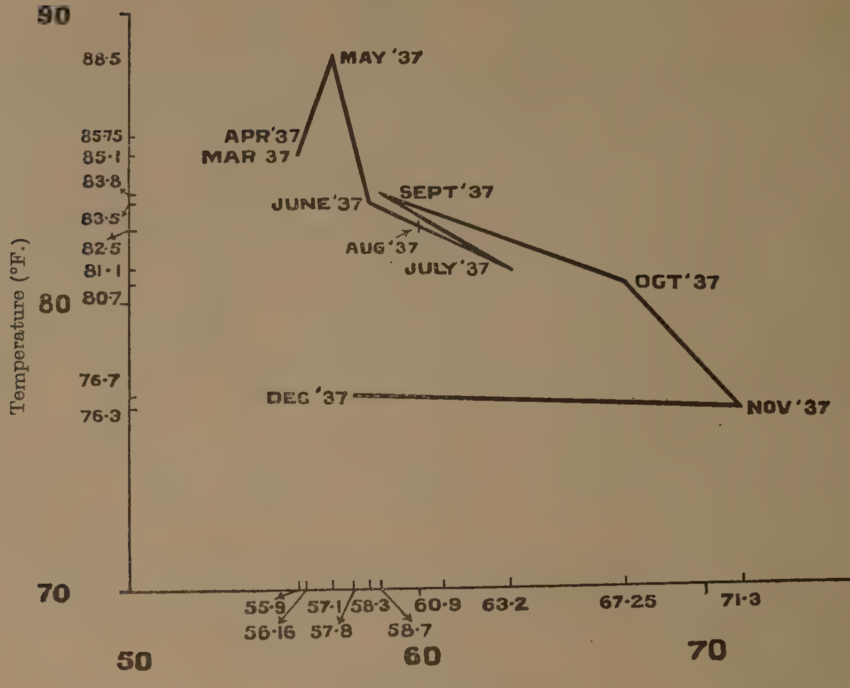

Fig. 2. Temperature-humidity curve, 1937

Habits of the adult

This species seems to be active both during day and night as seen from its behaviour in large outdoor breeding cages. During the bright sunny hours of the day they seem to take shelter in shady hiding places. These often rest on underside of leaves or in crevices in soils. The best time for their easy collection from outdoor cages has been during evenings just before sunset when they can ordinarily be pushed into tubes by small brushes. They are essentially shade loving and are in a way negatively phototropic as they readily move away from parts of tubes exposed to sunlight. Even winged adults pursue a zigzag flight and take rest away from lighted windows. They feed with avidity on nectar of flowers and are able to live for long periods as evidenced from their longevity records when fed on cotton flowers. Probably in nature their usual and natural food is nectar of flowers. They are also capable of living and reproducing to a slight extent without any food whatever.

Reactions to climate.—In outdoor cages and in open pits in fields while breeding on Bostrychids in cotton stalks, their activities are at the minimum during rainy days. No collection has been possible for some days after rains. They also dislike wet surfaces. Sometimes they display a peculiar habit of feigning death. When suddenly disturbed or shaken in a cage or forced to drop down, they remain still and motionless for a time as if dead, on their back with extended antennæ, but resume activity in two or three minutes. The activity of the males differs considerably from that of females. They either move about quickly in cages in search of females or for nourishment

They may also rest quietly for hours together on sides of cages, on stems or muslin covers and plugs

Parthenogenesis.—Virgin females after the usual pre-oviposition period readily oviposit and such eggs are seen to have a normal development. The progeny in all known instances of parthenogenesis invariably happened to be males. Eight virgins laid a total of 183 eggs out of which 24 adults (or 13·1 per cent) developed, all being males. Whereas the percentage of eggs that successfully developed out of 34 mated females was slightly higher, i.e. 19·6. Such variations may have been influenced by factors other than non-fertilization.

Occasional production of winged forms.—It has been observed that a small proportion of winged forms, particularly among the females appear occasionally which is a highly desirable feature for facilitating dispersal. Out of a total collection of 2,482 females there were only 272 winged (10·9 per cent). Winged forms among males have been very rare and only one winged form has been, during this long period, reared in the laboratory. Winged forms have been reared among the progeny of wingless ones.

Adult longevity.—These parasites are hardy insects which can stand strain and adverse conditions. Their longevity under optimum ecological conditions provided in the laboratory is seen to extend over five months (over 160 days). In order to study the relative length of life of the species, an extensive series of experiments running over several months during 1936-37 was conducted with a supply of various kinds of food. Nearly 300 adults of both the sexes, mated as well as unmated, mated females allowed to oviposit and otherwise, were experimented upon. Each individual was confined in a separate cage with a daily supply of the particular kind of food and daily observations were made until its death. The results are briefly summarised as follows :—The maximum record of longevity has risen to 162 days for an unmated male fed on nectar of cotton flowers. Unmated females have also lived up to 160 days on sugar solution. Such lengthened periods of life have been noted in a greater number of females than males. It has also been evident that unmated adults of both sexes generally show greater longevity than mated ones, the maximum for mated females and males being only 112 days each. The females are much more hardy and have been noted to live for pretty long periods even without food. The males on the other hand live only for a maximum of eight days without food. The greatest longevity, varying between 100 and 162 days, has been obtained with foods like cotton flowers, sugar solution, honey solution and raisin. In the matter of flowers, those of cotton appears to be the best among the few tested. The maximum longevity with cotton stems alone reaches 39 days. Females caged with a mere supply of host stages in cotton stems showed a maximum period of 39 days. This observation probably serves to prove that the adults do not feed on the body fluids of the host. With a daily supply of host stages in stems and food in the shape of honey, sugar solution or raisin the female longevity varied from 32 to 124 days averaging 61 days for 51 individuals.

Mortality in laboratory rearings

There are numerous factors that govern the rate of multiplication of the parasites in laboratory breeding experiments. Out of a total of 882 eggs laid

by a batch of 34 females it is seen that only 173 (19·6 per cent) adults successfully developed. The population increase during the first generation per 100 females comes to only 520 adults and only 53 per cent of these (i.e. 276) are females. But it has to be borne in mind that these factors may not necessarily be operating in nature and that the rate of increase under natural conditions may be consideraby higher than that observed under artificial conditions in the laboratory.

Total efficiency of the parasite

For 57 females tested in this series a total of 1,297 eggs were obtained, or 22·8 eggs per female. In other words every female by actual oviposition destroyed on an average (taking one egg per host as normal) nearly 23 hosts. Besides these, the same 57 females destroyed a total of 755 hosts by a process of mere stinging and paralysation which works up to 13·2 hosts per female. Every female, therefore, is seen to have actually destroyed on an average 56 per cent more of hosts than are oviposited upon. This is admittedly an important attribute of an efficient parasite which has to be taken into account when evaluating its total efficiency in nature.

Natural parasitism of the species in cotton fields, 1935-38.—For nearly three seasons during the period 1935-38, records of natural parasitism at the Cotton Breeding Station have been maintained as a routine part of the work. A few records have been obtained from other areas, such as Srivilliputhur in Ramnad district.* Thousands of cotton plants were collected and individually examined for every season so as to record the percentage of parasitism in relation to pest incidence. The rate of parasitism of this species alone has been always low and has never been seen to exceed one per cent (May, 1936). But one important point that has to be borne in mind is that this is the only parasite that occurs in some numbers during the first generation of the pest.

MASS-BREEDING OF THE SPECIES IN THE LABORATORY AND LARGE OUTDOOR CAGES

Scarcity of *Pempheres* during the greater part of the year necessitated an assiduous search for alternative hosts. A systematic and extensive collection and caging of all common stem borers and others belonging to various families, such as Curculionids, Cerambycids, Bostrychids, Bruchids, etc. was pursued. As a result, two alternative hosts were discovered--the common amaranthus-stem borer, *Hypolixus truncatulus*, and the Bostrychid borer attacking Cambodia stem, *Sinoxylon sudanicum*. The former weevil is a common borer of the weed amaranthus which is available in plenty at all seasons of the year. Though a convenient laboratory host, it was soon found that this host will not admit of any large-scale breeding of the parasites except for maintaining a small laboratory stock of the species. The other host was not very amenable for laboratory manipulation. By experiments it was discovered that green Cambodia plants pulled out and kept exposed in the open for two to three days served to attract these insects. This discovery proved to be of considerable use in an attempt at mass breeding. After a few experiments in the laboratory in small cages, large outdoor cages were devised

* The writer is thankful to Mr V. Margabandhu for the data from Ramnad district.

TABLE V

Spathius critolaus—*occurrence in nature*

Months	1935			1936			1937		
	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism
January	..	..	..	55·0	2·6	0·51	82·7	1·20	*nil*
February	..	..	..	74·0	2·6	0·26	89·9	0·67	*nil*
March	..	..	..	91·7	11·3	0·83	35·2	1·00	*nil*
April	..	..	..	88·2	1·7	*nil*	66·0	0·32	*nil*
May	..	..	..	98·7	3·0	1·0	82·3	0·32	0·16†
June	..	..	..	99·1	*nil*	*nil*	99·8	6·80	0·07†
July	..	..	..	100·0	*nil*	*nil*	89·1	3·80	*nil*†
August	..	..	..	100·0	*nil*	*nil*	100·0	2·70	0·04†
September	..	..	..	..	..	..	..	..	..
October	97·4 23·1	1·3 1·7	0·39* *nil***	..	..	..	12·85	1·00	*nil*
November	18·4	1·4	0·61	4·7	0·74	0·37	11·90	10·47	0·47
December	28·4	*nil*	*nil*	67·9	0·22	0·22	15·50	*nil*	*nil*

* Srivilliputhur area. ** Coimbatore area.

† These data were obtained from an off-seasonal crop sown in February 1937.

and substituted for the purpose. Large collections of fresh and slightly wilted cotton stalks were first stocked in such cages. Bostrychid adults were secured either from infested cotton stalks found in nature or by attracting the same to wilting plants kept exposed for the purpose. These beetles were introduced into the cages and allowed to bore and breed in the fresh material provided. After a period of about three weeks, when by examination the right types of host-grubs were found to occur, mated female parasites were liberated in the cages from the laboratory stock. In a fortnight to three weeks after liberation, adult parasites continued to emerge. This process was continued without interruption by artificial manipulation of the host so as to produce overlapping broods. The problem of the scarcity of *Pempheres* stages was thus partially solved. As many as 4,759 parasites have thus been bred.

Proportion of sexes

The proportion of sexes for a total collection of 2,732 adults from outdoor cages in 1936 was 52·4 per cent females and 47·6 per cent males. The winged forms among females work to 11·4 per cent. For a catch of 2,127 adults in 1937 the proportion of females to males was 56·4 per cent to 43·6 per cent. Winged females formed only 7·7 per cent among females. There was a solitary instance of a winged male in the rearing.

The proportion of males to females varied within a wide range during the different months. From 57·7 per cent females in March 1936 the number dwindled to 23·9 per cent in July. Thereafter these were on the increase. From 31·4 per cent in August the percentage rose to 63·7 per cent in December. From almost equal proportions in January 1937 the females dwindled to 37·8 per cent in April which gradually ascended to 60 per cent in December. As is the case with a number of other parasites, an automatic adjustment of the proportion of sexes is evident in this species with a view to ensure maximum reproductive capacity. When the proportion of females is large, i.e. when females are considerably in excess of males, parthenogenetic reproduction ensues in a large percentage producing only male progeny so as to raise the proportion of males. With the increase in males the females undergo a reduction in numbers. With increased opportunities for all females to get mated their productivity is increased and the females gradually rise in numbers so as to gain their normal proportions. It is not known whether such oscillations in the proportion of sexes is influenced by other factors, such as abundance or size of hosts, etc.

Experimental releases and recoveries in large field cages.—In order to gauge the possibility of increasing the efficiency of the parasite in nature, a few experimental releases of parasites in field cages were attempted. As pointed out already the parasite makes its appearance in the field during the first generation of the pest when the percentage of infestation is low. At this period the host-stages are not located far away from the surface of stems since the plants, being young, possess only thin and slender stems. Paucity of parasites at this period could be artificially remedied to some extent by keeping ready a stock of parasites by mass-breeding and liberation at the right time. A few experimental releases were planned and tried during the period. A preliminary trial in cages was attempted early in 1937 but this was vitiated since

the caged plants were heavily covered with ants, aphids and coccids. Since the parasites were readily attacked by the ants, this experiment was abandoned and a second trial was conducted in another cage towards the close of 1937. Plants were grown in this cage during September 1937. These plants were artificially infested by the introduction of a sufficient number of weevils. As weevils bred in cotton were not available at the time those obtained from alternate host plants, like *Triumfetta rhomboidea*, were utilized for infestation. It was later on discovered that only a very small proportion of the weevils had oviposited on these cotton plants. The infestation, therefore, was not heavy and the host stages were scarce. Yet liberations of parasites were made from November onwards till February 1938. Since only a small percentage of plants was found to be infested, only such plants as were, by external scrutiny, noticed to be attacked by a weevil were pulled out and examined month after month. The results of these examinations are presented in Table VI. From the figures it may seem that the infestations and percentages were sometimes high but the live stages happened to be comparatively few. The percentage parasitism was worked out on the basis of live and dead stages together as also on total infestations.

TABLE VI

Parasite releases and recoveries in cages

Months	No. of parasites released	Per cent of weevil attack	Percentage parasitism		Remarks
			As per stages	As per total infestations	
1937					
November	121	91·7	58·3	38·9	Live stages available for parasitisation were always much fewer than the infestation percentages might apparently indicate.
December	48	91·7	20·0	6·3	
1938					
January	23	100·0	21·4	17·6	
February	4	100·0	60·0	33·3	

It may be pointed out that no satisfactory conclusions can be deduced from this experiment owing to the development of the unexpected handicap mentioned already. It may, however, be inferred that a higher rate of parasitism can probably be induced in nature by repeated and large-scale releases of parasites at the proper time.

POTENTIALITIES

The life-cycle of the parasite covers normally a little over two weeks, whereas the pest multiplies comparatively slowly under field conditions having

a very long life-cycle occupying nearly seven to eight weeks. The parasites can theoretically accomplish nearly three generations before the host completes one. The average reproductive capacity of the parasite appears to be in no way inferior to that of the pest. Though the maximum egg capacity of the weevil, as recently observed, may rise as high as 164, the average capacity seldom goes above 24 eggs per female under optimum environmental conditions. The parasite on the other hand possesses an average capacity of 22 to 24 eggs. Considering the numerical equality in the proportion of sexes, the parasite can multiply rapidly and attain abundance in a short period so as to overtake the pest. Yet the rate of natural parasitism in cotton field conditions has never been seen to rise over one per cent. This may be due to a number of handicaps. The first and foremost among these may be located in the inherent habits and habitats of the pest. The most vulnerable part of its life is spent within the protected situation of the woody stem which is comparatively inaccessible. To some extent this handicap may be overcome by the presence of a comparatively long ovipositor in this particular species of parasite. A far more serious limitation is the restricted choice of victims. Parasitisation is possible only on a particular stadium in the life-cycle of the pest. Only medium-sized and mature grubs of the weevil are capable of being parasitised—the earlier and later stages being comparatively immune and the parasite may have to remain idle for long or short periods on account of the absence of the appropriate stages. Compensation for this to some extent may be found in the lengthened larval period and uneven development of the host, whereby, even in the first generation, grubs of varying ages may be found for long periods. In later generations considerable overlapping of broods occurs and suitable stages may be available at least in small numbers at all times. It is natural that such host stages may lie scattered in different plants located at short distances from one another. The parasite may not be able to explore any large area as it possesses only vestigial wings. This is another handicap operating against quick dispersal which is however mitigated to a great extent by the occurrence of a small percentage of winged forms, particularly among females. Another, perhaps more serious, difficulty is that the cotton season normally closes by the end of March, i.e. during the third generation of the host. By this time the live population of the weevil has already dwindled to very small proportions and to add to this the entire crop is removed and the parasite is confronted with the problem of tiding over the off-season. The entire absence of host stages in nature may constitute another drawback in its continued multiplication. This difficulty can be easily overcome in more than one way. Fortunately the adult life of the parasite is considerably prolonged, extending over five months under favourable conditions. It can therefore even survive a waiting period. Besides, the parasite can continue in nature at least in small numbers without extinction in an alternate host, like *Hypolixus*, which is available at all seasons. It can also maintain a small population on *Pempheres* itself which is now known to have a variety of alternate host plants. Many such alternate host plants have yielded this parasite, though in small numbers, in a variety of situations. Far more important than any of these is the facility afforded by the Bostrychid—*Sinoxylon*—for its easy multiplication so as to tide the off season. This Bostrychid freely breeds in wilting

Cambodia plants as also in those pulled out and stacked near cotton fields. By artificial manipulation of the broods, suitable stages for parasitisation can be continuously made available for pretty long periods.

Further there are a few other attributes of the parasite which are highly conducive to its efficiency. The occurrence of the parasite in most localities where the pest is found and its capacity to attack *Pempheres* in very nearly all of its alternate host plants is decidedly to its advantage. The parasite, so far as has been ascertained, is free from the attentions of any secondary or hyperparasite. Its capacity to destroy more hosts than are actually oviposited upon is another point in its favour. The discrimination displayed in the choice of the host from among healthy active ones and the economy practised in its oviposition tend to enhance its efficiency. Its eggs are evenly distributed and over a larger number of hosts and the wastefulness of many a parasites is eschewed. Its crowning attribute is that it attacks the pest in its first generation when the incidence is very low. The majority of host stages are easily accessible being nearer the surface in the stems because the plants at this stage are very young, tender and thin. Even a small percentage of mortality caused at the beginning of an outbreak is very effective because the weevil is known to multiply and build up its heavy population more by continuous breeding on the same crop rather than by any wave of immigrants. Since parasitism is restricted to only full-grown grubs it might be argued that the parasite begins to operate a day after the fair when the pest has completed its damage. This might be true in the case of other pests but not of this weevil. The initial percentage of incidence of this pest is usually low and the damage caused in the beginning of the season, though not negligible, is not appreciable. It is the potential increase of the damage as the generations advance that is a real source of danger which requires to be warded off. But the percentage of parasitism in nature at this stage is too low and inefficient to arrest the multiplication and spread of the pest. Yet the utility of even this small rate of parasitism cannot be ignored in the maintenance of the balance in nature. The problem is that in spite of possessing such favourable attributes it is still not an effective parasite in the field. The reason may be that the parasites are not numerically strong during this critical time which defect can be rectified by artificial means and the percentage parasitism increased as in experimental cages. The question of enhancing the efficiency of an indigenous parasite in its native environment is a great experiment in an unexplored line of investigation in this country ; and the present studies, despite the knowledge gained so far, are yet preliminary. There are a few instances of success in other parts of the world. The parasite certainly has possibilities and extensive trials with the parasite are worth making though success is not assured.

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THE ROLE OF FOOD AND ITS CONSTITUENTS ON THE PRODUCTIVITY AND LONGEVITY OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST.

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(With one text-figure)

Introduction

ALTHOUGH *Pempheres affinis* has been the subject of study for many years, and considerable knowledge has been accumulated on its general biology, comparatively little is known of the power of reproduction of the adult female. This is indeed surprising since it is the adult female's habit of oviposition on cotton that makes for its numerical abundance, destructiveness and economic importance.

It is recognised that physical conditions exercise a profound influence on the physiological activity of any insect, including its oviposition. The writers carried out some studies on the behaviour of *Pempheres* under controlled conditions of temperature and humidity*. In the course of such studies, considerable new light was shed on its ovipositional response. It was noted that its fecundity was increased to enormous proportions with a supply of certain kinds of foods, the physical conditions remaining the same. This observation led the writers to feel the imperative need of studying the nutritional physiology of the weevil, particularly in relation to its productivity. Such studies are deemed to be capable of yielding results of practical importance. They may afford clues for its successful control.

It is observed that some work has already been done on the subject of insect dietetics. These have been summarized by Uvarov [1928]. Among such contributions those of Larson and Fischer [1925] and Norris [1934] may be considered as pioneer investigations. Recent researches have also been largely directed towards an analysis of the effect of individual constituents of food on insect physiology ; and contribution on this aspect is already on the increase. Among these, the investigations on *Agrotis*, *Pyrausta* and *Loxostege* by Kozhantshikov [1938], on *Lucilia* by Dorman *et al*. [1938], on *Rhagoletis pomonella* byDean [1938], on *Aphids* by Evans [1938], etc. form some of the more important contributions. Among Coleoptera it is only the Tenebrionidae, Bruchids and Dermestids that have received some attention in this respect. These notwithstanding, the problem of the role of food

*The results of these studies are embodied in a separate contribution by the authors.

and its constituents on the fecundity and longevity of insects may be regarded practically as a virgin field and particularly so in regard to the group of insects known as weevils.

These considerations served to bring into prominence the need for the study of the character and composition of food-requirements, both qualitatively and quantitatively, of *Pempheres*. Some experimental work was therefore started as a mere preliminary to such studies by the middle of 1938. In pursuance of such studies the oviposition of over 100 females has been studied with a variety of foods and more or less identical physical conditions between the period of July to December 1938. It is the purpose of the present paper to record the results of these studies.

Review of previous work on *Pempheres*

Previous records dealing with oviposition of *Pempheres* are scanty. The few general references on its life-history yield very little data on its fecundity. This may be partly due to the fact that egg-laying records of the weevil are difficult to obtain. The eggs are laid concealed in cavities especially made in the bark of plants often without external indications in the form of scars. The earliest workers such as Lefroy [1908], Fletcher [1913], Ramakrishna Ayyar [1918], etc. are more or less silent over this aspect. Ballard [1923] has recorded an average egg capacity of 15·5 eggs per female with an average longevity of 16·7 days per female with a maximum of 30 eggs per female qualified by the remarks that in nature the egg-laying capacity may be greater. The present authors in the course of trials with about 500 females (1937-38) under controlled physical conditions noted a maximum of 121 eggs per female during a maximum life span of about three months, the average egg-laying capacity per female being 46.

Methods of study

The methods employed in the study of this aspect on this weevil by the present authors and those by previous investigators appear to be different. In cases where plants were exposed to weevils for oviposition in fairly large cages, the maintenance of the live plant in condition in cages and the microscopic examination of all the plant-parts would appear to be very tedious and uncertain. In the present studies the weevils utilised for experiments consisted of newly emerged adults from caged cotton stalks. The cages employed were 6 in. × 1 in. glass tubes with mouths plugged with clean cotton. Mating took place frequently throughout their life. Previous experiments by authors have shown that no difference in productivity or fertility is produced by isolation of males after a day or two or more. Instead of supplying entire plants for oviposition, small bits of fresh cotton stalks less than an inch in length were introduced into these cages. These were almost regularly removed after 24 hours or longer intervals and examined by careful dissection under a binocular. The daily counts of eggs were recorded. Fresh bits of stalks were supplied in the same manner. The specific food selected for trial was introduced into the cage and removed daily. These cages were kept under uniform conditions of temperature, humidity and light in the laboratory. Daily records of these factors were also maintained. Any difference in the eggs laid or longevity observed in each such set was therefore attributable to the differences in the nature, composition and quantity of the food supplied.

Very little is known about the feeding habits of the adult female. That the main source of the food of the adult weevil is the stem of cotton is apparent from the feeding punctures caused in stem apart from those made for egg deposition. Whether the female supplements it by feeding punctures on any other part of the cotton plant in nature has not been investigated.

Experiments with different kinds of food

All the trials were carried out under almost identical conditions of temperature and humidity within a narrow range from 81° to 83° F. and about 73 per cent relative humidity.

The oviposition and longevity of the insect were tested with the following foods :

Experiment I

With no artificial food.—Twelve pairs were tried under this head. No artificial food of any kind was supplied. The adults were deprived of even water. A small bit of fresh cotton stalk about an inch in length was supplied as a medium of oviposition.

The females laid an average of 4·01 eggs with an average life-span of 9·01 days. The maximum number of eggs laid by a single female was about 20. The maximum longevity recorded is about 15 days. Nearly 33 per cent females failed to oviposit.

Experiment II

Without artificial food but with a supply of water.—Twelve pairs were under observation in this series. The average number of eggs laid per female was 4·3 with an average life-span of eight days. The maximum number of eggs laid by a single female was about 11. It was found that the productivity has not been improved upon by a supply of water. On the other hand, maxima recorded for oviposition and longevity have decreased to a small extent.

Experiment III

With a supply of sugar solution.—Only seven pairs of adults were under trial in this category. These were provided with a daily supply of sugar solution by means of cotton wool soaked in the same.

It may be seen that an average of 25·3 eggs per female was deposited with an average life-period of 53·7 days. The maximum number of eggs laid by a female was about 41 and maximum duration of life nearly 62 days. There was no instance of a female that failed to oviposit. It is evident from the data recorded that the effect of a sugar diet on longevity as also on fecundity is very pronounced.

Experiment IV

With a supply of sucrose solution.—Twelve pairs of adults were kept under observation with a supply of sucrose solution as food.

There was an average number of 16·7 eggs with an average duration of life of 52 days per female. The maximum number of eggs laid by a single female has risen to 35 with a maximum longevity of 91

days. A small percentage, namely 8·3, of females failed to oviposit. Sucrose which is 100 per cent carbohydrate and said to possess great life-sustaining value has provided interesting data demonstrating the effect of an exclusive carbohydrate nutrition. In regard to longevity though the average does not show an increase, it is clear from the maximum of 91 days that the life-sustaining function of this constituent is remarkable. It has also clearly brought out that the productivity is diminished in that the average and the maximum number of eggs laid are decidedly lower than those with a sugary diet.

EXPERIMENT V

With honey solution.—Honey which is made up of 81·2 per cent carbohydrate and 0·4 per cent proteins was provided as food for a set of 12 pairs.

It has shown an average of 19·1 eggs with an average life duration of 30·3 days. The maximum number of eggs laid by a single female was 47. These data are of considerable interest when compared with sucrose or sugar diet. Honey which contains a trace of protein has shown a slight increase in the average productivity over sucrose though decidedly less than that with sugar. In the matter of maximum egg capacity, honey has produced such a high number as 47 as compared with 35 and 41 by sucrose and sugar respectively. The average life however is considerably reduced on this diet in comparison with sucrose or sugar. In the matter of reproductive capacity correlated with duration of life, honey diet is seen to be definitely superior to sucrose or sugar.

EXPERIMENT VI

With jaggery as food.—Jaggery was provided as food in the form of solution in cotton wool for a set of 12 pairs.

With this diet which contains a small proportion of protein, namely 0·6 per cent, the life-span is seen to be considerably reduced in comparison with sucrose, sugar or honey. But the egg-laying capacity is seen to have appreciably risen in both the average and the maximum.

EXPERIMENT VII

With molasses as food.—A series of 12 pairs was experimented on with a supply of crude molasses as food. This contains a higher proportion of proteins as also of impurities.

Molasses with about 2 per cent proteins and 69·3 per cent of carbohydrates has shown interesting results. The life-span is considerably reduced together with a reduction in average fecundity as compared with any of the other foods. This is probably due to the large amount of impurities which renders it easily susceptible to fungus. It has however significantly brought out the influence of the protein constituent by an appreciable rise in maximum egg-laying capacity to as high a figure as 60.

EXPERIMENT VIII

With a supply of raisin.—With a supply of entire raisin as food 12 pairs of adults were experimented upon.

An enormous increase in both fecundity and longevity has been noted. There was an average duration of life of 67·5 days with an average of 76·0 eggs per female. The maximum number of eggs laid by a single female has

risen to a record figure of 164 with a maximum longevity of about 136 days. Raisin containing 2·3 per cent proteins, 3·0 per cent fat and 68·5 per cent carbohydrates seems to be so far an ideal diet for this species. The importance of this diet, especially nitrogenous part thereof, has been amply demonstrated by these experiments.

Oviposition sites

It is believed that Coleopterous insects require, in addition to a generous food supply, suitable oviposition sites for stimulating egg-laying to the maximum capacity. Since *Pempheres* adults always make a number of feeding punctures before oviposition, the choice of oviposition sites may be influenced by the suitability of the tissue in the spot as food for the adult. To some extent the suitability of a site may also be governed by the nature of food available at the spot for the development of the grub that hatches out of the egg. It is known that the nutriment obtainable by a weevil may not only differ with different species of plants but also with the various parts of the same plant. Such differences in composition are stated to exist between the vegetative, flowering and other parts of the same plant. In order to see if differences in the choice of oviposition sites are due to variations in food value for the weevil adults, a series of trials with the various parts of cotton plant, such as roots, tender bolls, etc. was made.

Experiment IX

Oviposition and longevity with a supply of roots.—In this experiment, only roots were supplied in cages. Twelve pairs of adults were tried.

Eggs were laid at the cut end of the root caps leaving scars similar to those caused on stems. The eggs were not thrust deep into the roots. The average number of eggs laid was only 1·1 with an average duration of life per female of 7·5 days. A maximum of six eggs is noted for a single female. Nearly 66·6 per cent of the females did not oviposit.

Experiment X

With a supply of flower buds.—Thirteen pairs were experimented with. The only parts supplied as food as also for oviposition medium were flower-buds.

The eggs were deposited at the calyx region buried inside the petals. Punctures were noticed on the sepals. There was an average longevity of 8·1 days per female. The maximum number of eggs noted for a single female was only about nine. 42·6 per cent of the adults failed to oviposit.

Experiment XI

With a supply of tender bolls.—In this case only five pairs were under observation. Oviposition in these trials was very profuse as in one instance nine eggs and in another seven were noticed in a day. Egg-layings were confined to the calyx region where the bolls were soft and succulent. Numerous punctures were seen—sometimes as many as 40. Eggs were thrust into punctures made in the calyx and buried in the boll flush with surface of the boll. These were in most cases unsealed and visible. There was an average of 6·75 eggs with an average life-span of 8·2 days. A maximum of 12 eggs was seen deposited by a single female. Nearly 20 per cent of the adults failed to oviposit.

TABLE I

Effect of different foods on the longevity and fecundity of Pempheres

No.	Nature of food	No. of trials	Average eggs per ♀	Maximum eggs per ♀	Average longevity in days per ♀	Maximum longevity in days per ♀	Average post-oviposition period in days	Duration of egg-laying period in days	Rate of oviposition
1	2	3	4	5	6	7	8	9	10
1	Without food or water	12	4·0	20	9·0	15	3·9	2·3	2·7
2	Without food but with water.	12	4·3	11	8·0	11	4·6	1·4	3·4
3	Honey solution	12	19·1	47	30·3	52	4·8	21·3	0·9
4	Sucrose	12	16·7	35	52·0	91	16·0	20·3	0·8
5	Sugar	7	25·3	41	53·7	62	12·0	42·6	0·6
6	Jaggery	12	31·1	47	20·7	24	3·4	13·0	2·3
7	Molasses	13	13·5	60	16·1	21	3·0	9·0	2·0
8	Raisin	12	76·1	164	67·5	136	13·3	45·4	1·5
9	Roots	12	7·1	6	7·5	11	4·5	1·5	2·2
10	Flower-buds	13	2·5	9	8·1	11	4·1	1·1	4·0
11	Tender bolls	5	6·8	12	8·2	14	4·3	2·0	3·4

Discussion

Interesting data of considerable significance has been obtained from the series of experiments just described. The physical factors of temperature, humidity, light, etc., under which the several experiments were performed being more or less identical, the only variable factor involved in the experiments was the character and composition of the food supplied. On a comparison of the results obtained with the various foods, a wide range of variation is produced in regard to productivity and longevity by the nutrition afforded. It is evident from this that the weevils under favourable nutritional conditions are able to draw out in full their powers of reproduction. Table I presents the summarised results of all the experiments which are also expressed diagrammatically in Fig. 1.

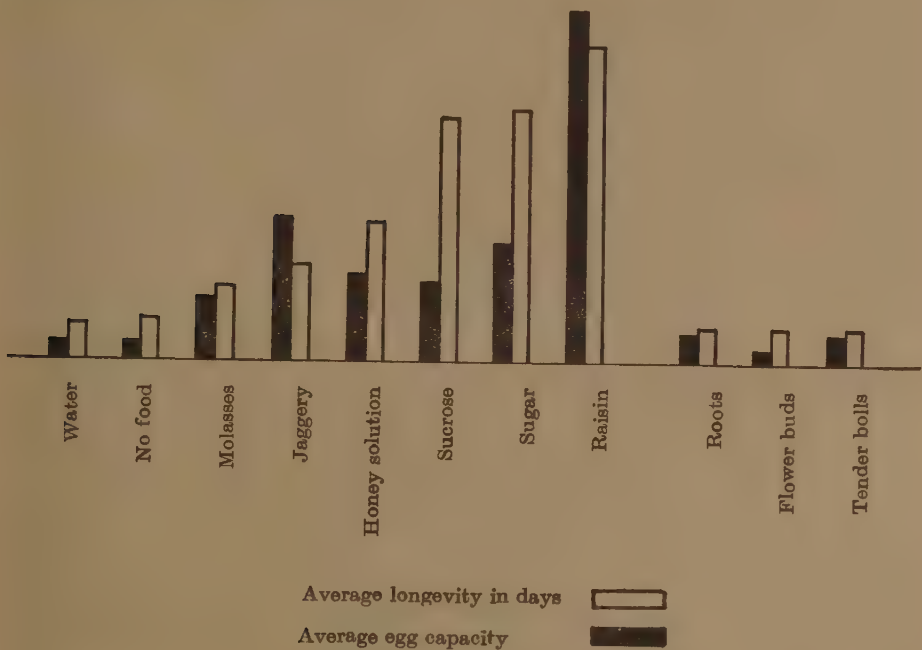

Fig. 1. Results of nutritional trials

Experiments without any supply of artificial food have shown an average of 4·01 eggs per female with an average life-span of 9·01 days. A mere supply of water produced an average of 4·3 eggs with a mean longevity of eight days. It is evident therefore that access to water has in no way increased the activities of the weevil. In the case of all the other experiments, a definite increase in both life-duration and egg-production is noticeable. It may therefore be inferred that both productivity and survival of the adult females are conditioned upon taking some food other than the cotton stalk supplied and that all the eggs are not developed at the time of emergence and the reserve of fat body does not suffice for full physiological functioning.

Leaving the experiment with raisin which is an extreme case, the other foods may be classed as predominantly carbohydrate in character. A comparison of the data on average egg-laying capacity with each of the remaining foods shows that jaggery stands foremost with 31·1 eggs, sugar coming next being followed by honey solution, sucrose and molasses in the descending order. The results assume a different aspect when the data of maximum egg-production are taken into consideration. Molasses with its slight protein content shows a maximum of 60 eggs and comes to occupy the first place ; jaggery and honey solution, each with a trace of protein, rank next and seem to have almost equal effect with 47 each ; sugar and sucrose which are exclusively carbohydrate foods come next in the series with 41 and 35 respectively.

On the other hand, the effect of these foods on the survival of the insects has yielded a different set of data. On the basis of average longevity those fed on sugar stand first with 53·7 days ; sucrose closely follows with a mean of 52·0 days. Sucrose—cent per cent carbohydrate—reveals the longest duration of 91 days. Sugar and honey appear to be the next best. Jaggery and molasses stand far behind the others in this respect. The length of life with the latter foods is much more abbreviated probably owing to the more rapid rate of oviposition in them as compared with sucrose, sugar or honey (Table I) wherein greater longevity does not proportionately enhance the productivity but only quicker exhaustion of the ovaries resulting in a prolonged post-oviposition period. Among the variety of diets tested in this series of experiments, raisin stands supreme and unique in the matter of mean as well as maximum longevity and oviposition. A record figure of 164 eggs is obtained as maximum with the highest average of 76·1 eggs and a longevity of 136 days or nearly 4½ months as maximum with 67·5 days as the average. It may be clear that no other food experimented with approaches raisin either in bestowing duration of life or egg-laying capacity.

It is evident from the results discussed that the explanation for such wide variation in productivity and life-duration is to be sought in the quantity and quality of the constituents of the diets. It is a generally accepted fact that the adult insects in general can sustain life on a carbohydrate diet but require proteins for the development of the genital products. Uvarov [1928] has summarized the literature on the subject and instanced several cases in support of the same. Mackerras [1933] experimenting on *Lucilia* has demonstrated the same. This is strongly supported by such phenomena in nature as the occurrence of voracious predators among females of several groups of insects and animals, by the habit of certain female hymenopterous parasites in feeding on the body-fluids of their hosts [Flanders, 1936]. The latter author has emphasised the great need of parasitic females for a protein diet since a carbohydrate diet is often available. It is generally recognised that no reproduction is possible without inclusion, at some time, of nitrogen in the diet. In the case of *Pempheres* the fecundity is not only increased by a nitrogenous food but also to a small extent by an exclusively carbohydrate diet. This is apparently in conflict with the results obtained by Norris [1934] in respect of *Ephestia* spp. She says that a diet of cane sugar increases the longevity of females of *Ephestia* but has no effect on its fecundity. Dean [1938] has arrived at the same conclusion in his studies on *Rhagoletis pomonella* (Apple maggot adults). He has found an increased number of eggs by adding

a protein food to sugar, while with sugar solution the length of life is increased but only a few eggs are laid.

The results obtained by the present writers are to a certain extent in conformity with those recorded by Larson and Fischer [1925] in their experiments with *Bruchus quadrimaculatus*. They have demonstrated that sugar feeding increases not only longevity but also fecundity. In the present trials the data show that a sugar diet has certainly augmented productivity besides life-duration over that obtained with no artificial food or with mere water. To this extent the writers agree with the findings of Larson and Fischer. Some of the latest researches on the subject seem to lend partial support to this inference. Kozhantshikov [1938] has proved that sugar nutrition in the case of *Agrotis* sp. and *Pyrausta nubilalis* has great influence not only on longevity but also on fecundity and fat reserves. Researches on the moth *Loxostege sticticalis* by Larchenko [1937] have shown that reserve fat is formed in the larval stage which is passed on to the adult stage in fatty tissue and supplementary feeding in itself does not provoke egg-maturation ; the latter is only possible when the fat body is dissolved and used by adult feeding. On the other hand Dorman *et al.* [1938] have shown that *Lucilia sericata* requires proteins for growth of ovaries and carbohydrate for long life of the adult stage. The data recorded by the authors with a raisin diet are in full accord with this finding.

The fundamental importance of a study of carbohydrate nutrition in general cannot be over-estimated since in nature large groups of insects are entirely dependent upon an exclusively carbohydrate food, like nectar of flowers. Such investigations would be of great interest, particularly in the face of such a conflict of opinions. In the absence of any further evidence it may be safe to conclude that while the effect of proteins in stimulating egg-production is undoubted there is evidence to show that carbohydrates are not without any importance in this respect. In the matter of longevity it is clear that a sugar diet has great influence in prolonging life.

From a study of the oviposition sites chosen by the weevil, some interesting though tentative conclusions can be drawn. Though *Pempheres* under pressure of circumstances may select any part of the food-plant for oviposition such as root, flower-bud, shoot or boll, oviposition is generally poor and life-span considerably reduced. It may therefore be inferred that though the weevil can utilise any part of plant as an egg-laying site, the necessary food and stimulus for development of eggs and continued life are not obtainable from these sites. These experiments also admit of the following inference. The cotton stem by itself is unable to supply either in quantity or quality some nutritional factor or factors necessary for normal egg-production which the weevil may perhaps be able to obtain from either other parts of the same plant or other species of plants. Further studies in the line are urgently needed for a fuller understanding of the problem.

Summary and conclusion

A series of experiments has been described to determine the effect of different kinds of food on the fecundity and longevity of *Pempheres* under nearly identical physical conditions. A convenient method of obtaining accurate oviposition record is given.

Table I is presented recording the results obtained in respect of various foods namely sucrose, sugar, honey, raisin, etc.

Mere supply of water does not seem to have any beneficial effect on its life-duration or reproductive powers. An exclusive carbohydrate diet is noted to produce a remarkable increase in longevity as also to a limited extent in fecundity. Molasses with its slight protein content has shown an increase in maximum egg-laying capacity over all foods except raisin. Raisin whose composition includes a small proportion of proteins and fats besides carbohydrates has yielded best results. It seems to constitute an ideal food among those tested in respect of all activities inclusive of fecundity and longevity. From an average of about four eggs without any artificial food as high an average as 76·1 eggs per female with a record number of 164 eggs as maximum per female has been obtained on a raisin diet. Results of a few experiments on oviposition responses in relation to oviposition sites such as roots, flower-buds, bolls, etc. are also presented.

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STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT) IN THE PUNJAB

I. VARIETAL SUSCEPTIBILITY AND DEVELOPMENT OF THE PEST ON DIFFERENT VARIETIES OF COTTON

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INTRODUCTION

JASSIDS are well known all over the world for the severe losses which they cause to a variety of economic crops. A number of species infest cotton. Thus we have *Empoasca facialis* Jac. in French Sudan [Vuillet 1925], Nigeria [Golding, 1928], Southern Rohdesia [Peat, 1928] and Uganda [Hargreaves, 1934]. *Empoasca flavescens* Fabre infests cotton in Philippines [Otanes and Butae, 1935].

In India, Lefroy [1906] mentioned jassids as a serious pest of several new American and Egyptian cottons in Bihar. Burt [1916] noted '*Empoasca gossypii*' (probably *Empaosca devastans* Distant) on some American cottons at Cawnpore. Misra [1919] mentioned *Empoasca notata* Melich as a pest of cotton in North Bihar. Vuillet [1925] stated that *Empoasca devastans* Distant and *Empoasca notata* Melich were the most dangerous of the less-known pests of cotton in British India. *Empoasca devastans* is also a pest of cotton in Madras [Ayyar, 1935]. Jenkins [1936] regards jassids as the most serious pest of cottons in Sind.

Of the species that infest cotton in the Punjab, *Empoasca devastans* Distant is the most serious and the commonest. It may be mentioned at the outset that *desi* cottons are practically immune to the pest and it is only the American varieties that suffer. There are of course marked varietal differences in the latter group as well and susceptibility to jassid attack is usually the chief limiting factor to the general cultivation of otherwise very desirable types. Several new strains of American cottons recently evolved by the Cotton Research Botanist, namely 36F, 38F, 58F and a host of others, although very desirable from the agricultural point of view, are not being pushed into general cultivation on account of their susceptibility to jassids. Records also show that during 1913-14 the failure of 3F cotton, the first variety of American cotton introduced into this province, was due to the ravages of this pest. In fact it is true to say that no variety of American cotton will be a commercial success in the Punjab unless it is resistant to jassids.

So far it has not been possible to control this pest by chemical and mechanical means [Sloan, 1938]. The pest also does not suffer to any great extent from the attack of predacious and parasitic enemies. The only hope, therefore, lies in the discovery of a resistant variety of cotton.

The problem

During 1937 and 1938 work was confined to the investigation of the following two aspects of the problem:

1. The differences in susceptibility to jassid infestation among different important varieties of cotton.
2. The causes of the inability of the insect to infest some varieties.

Comparative jassid population on different varieties of cotton at Lyallpur

Detailed records of the annual prevalence of jassids on different varieties of cotton in the Punjab before 1936 are rather scanty. The only published records in this connection are those of Lal [1937] who mentioned that the resistance of 43F (now called 289F/43) against jassids, though higher than that of some very susceptible varieties such as 38F, 45F and 289F, is not so high as that of 4F and that the resistance of Jubilee cotton though higher than that of the American varieties is about the lowest among the *desis*.

Preliminary observations soon showed that an ideal census of jassids, taking into account all the stages, i.e. eggs, nymphs and adults was practically impossible. The eggs are laid in the leaf-veins and it is impossible to examine and count their number in field samples. The nymphs and adults could be recorded on leaves, but owing to vital differences in their habit, their relative numbers could not be determined by absolutely identical methods.

A survey of literature showed that the commonest method of recording jassid population has been either to collect adults by sweeping and count them or count the living nymphs on a number of leaves. Sweeping method has been severely criticised by Delong [1932]. According to him, samples of insects collected by this method from various situations would vary with the prevailing conditions such as temperature, humidity, wind velocity, position of the operator in relation to the wind, position of the sun and size and condition of the crop. He came to the conclusion that, at best, this method could only give a very rough and an inaccurate estimate of the comparative insect population.

Jassid population was determined in a field at the Cotton Research Botanist's farm at Risalewala (Lyallpur) where the following varieties had been sown in contiguous plots measuring 21 ft. × 171 ft. during 1937 and 1938 :—

289F/43, LSS, 289F/K 25, 4F, 100F and Jubilee cotton.

The plots were sown on 14 May each year and received identical cultural treatments such as irrigation, hoeing, etc. Each variety was replicated seven times according to Fisher's randomized block system. During 1937, observations were recorded in all the plots, but during 1938 only five replications of each variety were taken into consideration. The following methods were tried :

Sweeping

Sweeping was conducted with a hand-net 13 in. in diameter and having a terminal tubular muslin bag 27 in. long and with a wooden handle 27

in. in length. Sixteen forward and sixteen backward semi-circular sweeps, as far as possible, over the same distance were made on the cotton plants in the middle rows of each plot, thus making a total of 224 sweeps for each variety during 1937 and 160 during 1938. Full cognizance was taken of De-long's criticism of this method and the following precautions were taken :

(*i*) As far as weather conditions permitted, the sweepings were done in the morning hours only and the work finished in a reasonably short time.

(*ii*) The direction of the sweeps was always against the wind.

(*iii*) Sweeping on adjacent plots, one after another, was avoided.

(*iv*) The operator and the appliances were the same throughout.

The total number of jassid adults collected in each day's sweepings during 1937 and 1938 are given in Tables I and II.

TABLE I

Jassid adults counted on different varieties of cotton by sweeping, 1937

Date of observation (1937)	Number of jassid adults counted in 224 sweeps of hand-net				
	LSS	4F	289F/43	100F	289F/K25
June 8	..	..	..	..	2
,, 15	..	1	1	1	2
,, 22	..	2	3	4	5
,, 29	3	4	3	4	6
July 5	5	4	4	7	21
,, 12	26	32	33	46	74
,, 19	44	60	57	57	101
,, 26	122	135	144	169	276
Aug. 2	252	276	300	315	560
,, 9	438	480	564	630	927
,, 16	584	742	776	823	1176
,, 27	778	881	946	976	1663
Sept. 4	1087	1260	1186	1320	2281
,, 10	992	1079	1074	1170	1967
,, 17	534	670	718	863	1366
,, 23	345	466	530	589	802
Oct. 1	201	226	309	336	606
,, 8	142	145	200	254	460
,, 15	61	67	79	96	186
,, 22	40	57	59	94	156
,, 31	23	26	34	57	89
Nov. 5	12	10	31	32	59
,, 12	6	11	15	20	28

TABLE II

Jassid adults counted on different varieties of cotton by sweeping, 1938

Date of observation (1938)	Number of jassid adults counted in 160 sweeps of hand-net					
	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
June 7	..	..	..	..	..	..
,, 15	..	..	..	..	1	..
,, 22	..	..	..	..	..	6
July 1	..	4	..	..	3	12
,, 6	..	..	..	1	2	8
,, 13	4	3	10	8	10	24
,, 21	17	22	20	28	20	78
,, 26	12	8	13	10	19	109
Aug. 3	9	16	13	24	23	149
,, 10	27	30	37	38	55	186
,, 17	32	36	34	43	58	200
,, 23	24	36	28	54	41	201
,, 30	24	38	37	57	46	206
Sept. 5	32	49	44	61	60	235
,, 13	17	29	22	26	29	222
,, 21	4	15	14	13	14	145
,, 28	..	16	11	11	13	101
Oct. 5	6	12	9	8	9	82
,, 12	2	11	4	12	9	52
,, 19	2	14	7	9	16	41
,, 26	..	10	2	13	9	41

COUNTING OF LIVING NYMPHS ON THE LEAVES OF PLANTS IN THE FIELD

Two plants of normal size and growth were selected at random in each plot at each observation and the adults and nymphs carefully counted by

slowly turning over the leaves. Thus during 1937, 14 plants of each variety were examined and 10 in 1938. As most of the adults flew away, the number of nymphs only counted by this method during 1937 and 1938 are presented in Tables III and IV.

TABLE III

Jassid nymphs counted on different varieties of cotton, 1937

Date of observation (1937)	Total jassid nymphs counted					
	No. of plants counted	LSS	4F	289F/43	100F	289F/K25
21 June	14	1	..	1	2	5
28 ,,	,,	1	3	2	2	9
5 July	,,	2	4	4	7	10
12 ,,	,,	19	20	3	21	41
19 ,,	,,	29	46	38	48	60
26 ,,	,,	74	74	92	104	186
3 Aug.	,,	108	151	145	230	427
10 ,,	,,	152	222	221	266	592
17 ,,	,,	194	289	339	300	873
28 ,,	,,	190	221	239	276	622
10 Sept.	,,	156	178	223	253	645
17 ,,	,,	102	160	180	209	479
23 ,,	,,	80	106	106	170	390
1 Oct.	,,	60	83	81	103	280
8 ,,	,,	45	43	82	120	379
14 ,,	,,	24	35	32	33	100
22 ,,	,,	26	27	40	49	112
31 ,,	,,	36	39	43	60	79
5 Nov.	,,	18	21	34	38	45
12 ,,	,,	4	9	2	12	27

TABLE IV

Jassid nymphs counted on different varieties of cotton, 1938

Date of observation (1938)	Jassid nymphs counted						
	No. of plants counted	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
7 June	20	..	..	..	..	..	..
15 "	20	..	..	..	..	..	1
22 "	12	..	..	1	1	..	5
1 July	15	..	..	1	1	..	2
6 "	20	..	..	..	..	2	19
13 "	10	2	1	3	1	3	29
21 "	20	1	3	2	2	4	52
26 "	10	2	2	..	2	6	102
3 Aug.	10	..	6	3	5	5	124
10 "	10	4	8	3	6	11	90
17 "	10	4	5	12	5	14	88
23 "	10	4	8	14	10	17	140
30 "	10	5	12	16	9	11	156
5 Sept.	10	8	13	16	17	22	162
13 "	10	4	7	7	17	13	108
20 "	10	1	4	4	13	6	82
28 "	10	1	9	6	8	8	61
5 Oct.	10	1	3	1	5	11	46
12 "	10	..	5	4	8	4	56
19 "	10	1	2	2	1	9	38
26 "	10	..	2	2	4	5	26

COUNTING OF ADULTS AND NYMPHS AFTER FUMIGATING THE PLANT

Two normal plants were selected as before in each plot and smartly enclosed in a fumigating chamber. Before enclosing the plants white sheets of paper were spread underneath. The insect life was killed by pumping calcium cyanide gas from the top of the chamber. The dead insects were counted both on the leaves and on the white paper. Shaking the plants was specially avoided. The total number of nymphs and adults counted on plants of different varieties during 1937 and 1938 are presented in Tables V and VI.

TABLE V

Estimation of jassid population on different varieties of cotton at Lyallpur by fumigation, 1937

Date of observation (1937)	No. of jassid adults and nymphs counted on 14 plants				
	LSS	4F	289F/43	100F	289F/K25
8 June	..	2	..	..	2
16 ,,	..	2	1	2	5
23 ,,	4	4	4	3	12
30 ,,	4	5	7	7	18
6 July	16	10	12	13	40
13 ,,	27	44	44	47	92
20 ,,	54	57	59	77	130
27 ,,	138	141	137	174	276
4 Aug.	178	199	214	319	605
11 ,,	237	278	279	334	739
18 ,,	280	346	381	303	1082
28 ,,	319	369	383	476	1156
4 Sept.	419	477	511	590	1169
11 ,,	283	316	421	458	945
18 ,,	200	261	265	365	659
24 ,,	125	143	191	292	429
2 Oct.	80	117	174	171	400
9 ,,	91	84	87	140	329
15 ,,	71	72	66	105	189
23 ,,	63	73	86	90	170
30 ,,	42	56	84	87	131
6 Nov.	13	18	21	46	67
13 ,,	11	12	9	13	20

TABLE VI

Estimation of jassid population in different varieties of cotton at Lyallpur by fumigation, 1938

Date of observation (1938)	No. of jassid adults and nymphs counted on 10 plants					
	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
15 July	3	5	8	6	7	46
23 ,,	4	5	5	7	6	76
28 ,,	4	3	2	5	10	109
4 Aug.	1	14	7	10	9	133
12 ,,	3	13	6	8	10	103
19 ,,	7	9	17	12	12	130
25 ,,	7	23	17	14	18	174
1 Sept.	9	26	23	19	21	203
7 ,,	6	21	20	20	45	207
16 ,,	4	9	11	15	15	131
24 ,,	2	3	12	9	10	95
30 ,,	1	3	1	3	4	76
7 Oct.	1	2	3	4	4	56
14 ,,	1	5	2	8	12	46
21 ,,	..	5	7	7	11	41
28 ,,	..	5	8	4	8	28

A detailed statistical examination of these tables has been made and very interesting conclusions have been arrived at. The comparison of different varieties, so far as resistance or susceptibility to this pest is concerned is, therefore, not dealt with here, but will be found in the appendix.

A comparison of the figures obtained in the two years shows that the incidence of attack was much higher in 1937 than in 1938. While comparing the tables of any one method it has to be kept in view that although different units—for example number of sweeps or the number of plants—had been employed, yet even after accounting for this, the incidence would be see to be much higher in the former year.

The data also show that the maximum prevalence periods of jassids were fairly constant in time, in both the years ; the highest infestation was noticed from the end of August to the second week of September.

The efficiency of the various methods tried will be dealt with in the appendix. A few general observations are, however, given here.

Sweeping was found to be very satisfactory for adults. Our work is not open to the objections raised by Delong [1932], as the various plots in which population was recorded were contiguous and all the operations were conducted in an identical manner in a reasonably short time on the same day. The factors that affected one plot also affected all the others to practically the same extent. Sweepings of any one day were, therefore, quite comparable.

Counting the insects in living condition on the plants was found to be good for nymphs but not for adults which invariably flew away. In this case it is essential that the operation should be conducted very calmly without shaking the plants too much as older nymphs also have a tendency to hop off, if disturbed. This method, however, depends too much on human factor.

Fumigation is a fairly reliable method both for adults as well as for nymphs. Lal [1938] regards this method satisfactory for adults but not for nymphs. Our method of working differed from his in that we counted the insects on the foliage and avoided too much shaking of plants. This was done because even after vigorous shaking quite a large number of insects remained sticking on to the plant parts. On the whole we found it more satisfactory to count the insects *in situ* rather than to try to collect them on the paper spread below the plant. Moreover, if shaking is resorted to, there is always a possibility of a number of smaller nymphs being blown off the paper where they cannot be distinguished from dust particles. We fully agree with Lal [1938] in the view that ' jassid attack is not uniform in the cotton fields' and ' the accuracy of population estimation of this insect should depend on a large number of samples drawn from all parts of the fields '.

Development of jassids on different varieties of cotton

Developmental studies were carried out on both *desi* and American varieties. Amongst the latter, both resistant and highly susceptible varieties were included. The aim in view was to find out the differences, if any, in the behaviour of the insect on different types of hosts. The following experiments were performed :

To determine the percentage of development of Empoaca devastans *nymphs to adult stage on different varieties of cotton*

Equal number of 1st instar nymphs collected from *bhindi* (*Hibiscus esculentus*) plants were caged on the following varieties seven times during 1937 and four times during 1938 :

Jubilee cotton
39 Mollisoni
LSS
4F
289F/43 and
38F

Of these, the first two are *desi* varieties and most resistant while 38F is the most susceptible of all the American strains. The rest are fairly resistant. At

each observation three plants of the same age of each variety growing in pots were selected and covered separately with wire-gauze jassid-proof cages. The leaf-area offered for each variety was kept approximately the same. The nymphs were handled with a camel-hair brush and unless a nymph moved off after liberation it was not considered healthy and was rejected. The number of these developing into adults was determined daily. Table VII gives a summary of the results.

TABLE VII

Nymphal development on different varieties of cotton

Variety	Total nymphs liberated		Total adults emerged		Percentage of success	
	1937	1938	1937	1938	1937	1938
LSS	900	315	691	274	76·7	86·9
4F	900	315	719	272	79·8	86·9
289F/43	900	315	723	262	80·0	83·1
38F	900	240	732	202	81·3	84·1
289F/K25	..	315	..	272	..	86·9
39 Mollisoni	900	315	700	209	77·3	66·3
Jubilee cotton	900	315	698	254	77·5	80·6

The above experiments showed that the nymphs of *E. devastans* can flourish equally well on all cottons, susceptible or resistant. This work confirms some previous observations on the subject by Husain [1937] who experimented with different varieties. Peat [1926-27], working on *E. facialis*, is also of the view that jassid nymphs if forced to remain on plants of Cambodia cotton, a highly resistant strain, can live and cause symptoms of attack on plants that are practically immune in the field.

To determine the comparative number of eggs laid on desi *and American varieties of cotton by equal number of* Empoasca devastans *females*

During 1937, equal number jassid females that had not oviposited before were confined on leaves of plants of all the varieties mentioned above. These plants were growing in pots and were sown on the same date. The insects were allowed to oviposit on one leaf for 24 hours, after which fresh leaves were provided. This was continued as long as even one jassid female survived. The total number of eggs laid by each set of females was determined by removing the leaves that had been oviposited upon each day and dissecting the leaf veins carefully under a high power binocular. The results are summarised in Table VIII.

Table VIII

Number of eggs laid on different varieties of cotton in 1937

No. of jassid females	Period of experiment	Eggs laid on different varieties					
		LSS	4F	289F/43	38F	39 Mollisoni	Jubilee cotton
5	9 to 20 July	33	26	35	45	6	8
5	13 to 26 July	25	34	33	42	11	6
5	21 July to 6 Aug.	32	36	39	47	5	6
5	4 to 21Aug.	44	45	53	57	9	14
5	7 to 27 Sept.	50	54	31	54	9	12
5	1 to 23 Oct.	32	37	27	55	8	10
5	9 Nov. to 11 Dec.	16	15	17	15	1	2

The comparative number of eggs laid on different varieties of cotton were tested yet in another manner. Three plants of each variety sown on the same date in separate pots were selected. An attempt was made to select an equal quantity of leaf material for each variety. The plants were covered with jassid-proof wire-gauze cages and equal number of jassid males and females caught from *bhindi* (*Hibiscus esculentus*) plants were liberated on each plant. The nymphs hatching out each day from each plant were counted. The results are given in Table IX.

Table IX

Comparative number of jassid nymphs hatching on different varieties of cotton during 1937

Duration of experiment	Total females liberated	Jassid nymphs hatched on different varieties					
		LSS	4F	289F/43	38F	39 Mollisoni	Jubilee cotton
5 to 28 July	60	69	96	94	101	20	23
2 to 30 Aug.	60	92	90	91	81	17	22
5 Sept. to 2 Oct.	60	112	131	95	134	28	31
7 Oct. to 8 Nov.	60	61	55	69	92	15	15
13 Nov. to 20 Dec.	45	35	46	47	53	10	9

In the above experiment it is possible that many of the females may have oviposited before, but the results could not be vitiated by this fact as this factor was the same for all the varieties. The object of the experiment was only to compare the relative ability of the females to oviposit on *desi* and American strains. It cannot be believed that the fact that fewer eggs were always laid on the former was due to the females having oviposited before. Evidently the factor responsible for this lay more in the plants rather than in the insect.

During 1938, a suspicion arose that although the females may sometimes oviposit freely on the *desi* strains, yet some of the eggs may not hatch. To test this, the hatching percentage of eggs on different varieties of cotton and on *Hibiscus esculentus* which is the most favoured host of this insect in the Punjab was determined in the following manner.

Equal number of jassid females, as before, were liberated on leaves of different varieties of cotton and *bhindi* as in 1937 and the number of nymphs hatching out from these was determined. The unhatched eggs were counted by dissecting the leaf-veins after the nymphs had ceased to emerge. The egg shells shrivelled up and became transparent after hatching and could not be distinguished from the leaf-tissues but an unhatched egg could be made out for sometime owing to the presence of yolk in it. The results obtained are summarised in Table X.

TABLE X

Hatching percentage of jassid eggs laid on different varieties of cotton and bhindi *in 1938*

Host plant	No. of females used	Total eggs laid	Total nymphs hatched out	Hatching percentage
39 Mollisoni	40	33	33	100
Jubilee cotton	40	47	47	100
289F/K25	40	290	286	98·6
38F	40	265	263	99·2
4F	25	154	150	94·3
289F/43	30	157	153	97·4
LSS	35	180	174	96·6
Bhindi	40	503	495	98·4

The following conclusions can be drawn from the experiments described above :

(1) There is a marked reduction in the number of eggs laid by the jassid females on *desi* cottons.

(2) Jassid eggs even when laid in the leaf-veins of immune varieties (*desi*) have no difficulty in hatching.

(3) That the number of eggs laid by jassid females vary with the host-plant. The oviposition is more free on *bhindi* than on cotton plants. This may partly explain the reason for the very severe jassid infestation on this plant throughout the season.

Our results confirm previous observations on the subject [Husain, 1937; Lal, 1937]. Sloan [1938] is also of the view that 'resistance is partly due to the unsuitability of the plant for jassid breeding and partly to its ability to tolerate the pest'.

It is now abundantly clear that causes of resistance or susceptibility of varieties of cotton to this pest must be sought in the leaf-veins [Lal, 1937]. Further work is now being directed to the solution of this problem.

Summary

Jassids are a very serious pest of American cottons in the Punjab. *Desi* cottons are, however, practically immune to it. The species of jassids most prevalent is *Empoasca devastans* Distant.

The first problem tackled was to devise a reliable and quick method for estimating the comparative infestation on different varieties. It has been shown that sweeping with hand-net answers this purpose quite well.

Varietal differences were observed in the case of American cottons. Of the commercially important varieties, LSS was found to be most resistant and 289F/K25 most susceptible. Other varieties, namely 4F and 289F/43, came in between these two extremes in the order mentioned here.

It has been shown that the chief difference between the comparatively resistant or susceptible varieties lay in the number of eggs laid in the leaf-veins of these strains. The eggs when once laid had, however, no difficulty in hatching and the nymphs of all stages also could feed and reach normal maturity on all cottons equally well.

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APPENDIX

An accurate method of insect census is one of the most desirable and at the same time a very difficult matter in economic entomology. During the course of the present work emphasis was laid on this aspect of the problem and the three methods mentioned in the text were employed on a large number of varieties for two seasons. The data are presented in Tables I—VI in the text. A detailed statistical examination of these data has been made.

Since the infestation of jassids on different varieties showed a high correlation the significance of the mean difference between any two was found by the help of equation (i) where the standard error of the mean difference was calculated by equation (ii).

$$\text{(i)}\quad t=\frac{(\bar{y}-\bar{x})}{SE_{(\bar{y}-\bar{x})}}$$

$$\text{(ii)}\quad SE_{(\bar{x}-\bar{y})}=\sqrt{SE^2_{\bar{x}}+SE^2_{\bar{y}}-2r_{xy}\cdot SE_{\bar{x}}\cdot SE_{\bar{y}}}$$

where $\bar{x}$ and $\bar{y}$ represent the mean infestation on any two varieties and r_{xy} is the coefficient of correlation between the two [Treloar, 1935].

The average seasonal infestation on different varieties is given in Table XI.

Table XI

Average seasonal infestation of jassids on different varieties

Varieties	1937			1938		
	Sweeping	Counting	Fumigation	Sweeping	Counting	Fumigation
Jubilee cotton	...	...	...	10·60± 2·60	1·90 ±0·50	3·31±0·69
LSS	247·6±69·5	66·05±14·29	126·43±25·74	17·45± 3·23	4·50± 0·89	9·44± 1·94
4F	288·4±80·0	86·55±19·46	146·76±30·00	15·25± 3·14	4·85± 1·19	9·31± 1·70
289F/43	307·7±80·2	95·35±21·90	162·62±33·10	20·80± 4·44	5·75± 1·18	9·44± 1·31
100F	341·9±87·5	115·15±23·43	195·71±37·50	21·85± 4·40	7·55± 1·33	12·63±2·45
289F/K25	557·1±144·0	268·05±59·29	412·29±85·04	104·90±18·27	69·35±11·35	103·38±14·14

It will be seen from this table that the varieties Jubilee cotton, LSS, 4F, 289F/43, 100F and 289F/K 25 were placed in an ascending order, Jubilee cotton (a *desi* strain) being the least susceptible. Amongst the American strains LSS was found to be very resistant and 289F/K25 highly susceptible.

In order to find out whether the differences between the different varieties were significant or not, the values of '*t*' were calculated and are given in Table XII.

Table XII

Values of ' t '

Varieties compared	1937			1938		
	Sweeping	Counting	Fumigation	Sweeping	Counting	Fumigation
Jubilee cotton vs. LSS	...	...	...	5·04**	4·48**	4·06**
Jubilee cotton vs. 4F	...	...	...	4·84**	3·60**	4·88**
Jubilee cotton vs. 289F/43	...	...	...	4·49**	4·14**	6·81**
Jubilee cotton vs. 100F	...	...	...	5·59**	6·14**	4·33**
Jubilee cotton vs. 289F/K25	...	...	...	5·86**	6·15**	7·37**
LSS vs. 4F	3·40**	3·33**	3·99**	2·15*	0·53	0·07
LSS vs. 289F/43	2·06	3·49**	3·94**	2·11*	1·69	0·00
LSS vs. 100F	4·41**	4·91**	4·91**	2·49*	3·72**	1·42
LSS vs. 289F/K25	4·11**	4·42**	4·75**	5·70**	6·11**	7·47**
4F vs. 289F/43	2·68*	2·02	2·74*	3·07**	0·95	0·16
4F vs. 100F	4·73**	4·46**	4·28**	4·28**	3·33**	1·93
4F vs. 289F/K25	4·13**	4·36**	4·76**	5·79**	6·17**	7·34**
289F/43 vs. 100F	3·80**	3·39**	3·61**	0·64	1·92	1·57
289F/43 vs. 289F/K25	3·80**	4·53**	4·72**	5·78**	6·04**	5·09**
100F vs. 289F/K25	3·73**	4·15**	4·28**	5·73**	5·98**	7·30**

*denotes significance up to 5 percent level.
**denotes significance up to 1 per cent level.

Some of the interesting features which are brought forth from Table XII are given below.

Comparison of different varieties

It will first be recalled that the degree of infestation during 1937 was much higher than in 1938. No suitable explanation exists for this phenomenon, except possibly the dryness of the atmosphere during the latter year. Our knowledge of the bionomics of this pest is very meagre and, therefore, the causes of the differences in the infestation in different years is at present a matter of conjecture. It is, however, hoped that the work now in progress will throw some light on this phenomenon.

It will be seen from Table XII that Jubilee cotton (a new type of *desi* cotton with lint approximating to American 4F) is the least susceptible type

of all cottons. LSS appears to be the most resistant American variety with 4F next in order. The difference in the susceptibility of 4F and 289F/43 is doubtful while the latter variety appears to be somewhat better than 100F and 289F/K25. In its own place 100F is better than 289F/K25 which is definitely the most susceptible variety under the soil and climatic conditions obtaining at Lyallpur.

Comparison of the three methods

It is quite clear from Table XII that the level of significance of practically all the varieties is the same by the three methods. There are of course slight discrepancies here and there, but these are not such as to cast grave doubts on the similarity of the three methods. This finding is very interesting as now we can employ any one of these methods instead of all the three, and thus save great deal of time and labour. As the counting of living nymphs and fumigation are very time-consuming operations these can be discarded in favour of sweeping. By this method alone the comparative infestation of the different varieties can be accurately determined.

It can also be seen that in years of high infestation, like 1937, the differences between the varieties are brought out much more clearly than in years of low infestation. This is of course to be expected as the experimental error will proportionately be higher when the number of insects dealt with is small.

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STUDIES ON *SCHISTOCERCA GREGARIA* FORSK.

*X. ROLE OF WATER IN THE BIONOMICS OF THE DESERT LOCUST

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I. Introduction

Of the physical environmental factors, temperature and moisture have decidedly the most potent influence on the life-activities of all insects, and for denizens of arid regions, such as the desert locust, moisture is undoubtedly of fundamental importance.

Schistocerca gregaria normally gets its supply of water through food, but when this supply is insufficient and loss of moisture from its body is excessive, the locust will gnaw up any wet substance, even moist wool, though of little nutritive value and thus appease its craving for water [Husain and Mathur, 1936]. According to Buxton [1924], during periods of drought, desert insects obtain the necessary amount of moisture by feeding on 'apparently dry' fragments of plants, as the latter contain a fair amount of moisture absorbed from the saturated, or almost saturated, atmosphere of the cool desert nights. Swarms of locust, after long marches, have been observed to drink water as such [Nikolsky, 1925].

The mass multiplication of locusts, and the consequent development of the so-called 'gregarious' phase, is certainly connected with precipitation. Myriads of hopper bands cannot come into existence in the absence of an abundance of vegetation. Precipitation brings about the conditions of soil-moisture and atmospheric humidity necessary for the luxuriant growth of desert vegetation, which must always precede the mass multiplication of *Schistocerca gregaria* [Husain, 1929] in their permanent home. Ballard and his co-workers [1932] observed this during the last desert locust invasion. They state, 'In most years there is insufficient moisture and food in Sinai (Egypt), to support large swarms of hoppers. The peculiar feature of the present year (1929-30) was the very abundant winter and spring rainfall all over Sinai'.

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* For previous parts see *Ind. J. Agric. Sci.,* 1933, 1936 and 1937.

† This investigation was conducted at the Locust Research Laboratory, Punjab Agricultural College, Lyallpur.

F om his locust survey work in the permanent breeding grounds of *Schistocerca gregaria* in North India, Rao [1929] came to the conclusion that the essential conditions or the breeding and multiplication of locusts and the origination of new locust cycles appeared to be widespread and heavy rain in Iran and Baluchistan in winter followed by heavy and well-distributed rainfall during the monsoon period in the deserts of Sind and Rajputana.

From Bodenheimer's observations [1929] on the life-duration of the starving individuals of *Schistocerca gregaria* at several relative humidities, Uvarov [1931] arrived at the conclusion that higher humidities were favourable for the hopper stages. Hamilton [1936] showed in three species of locusts (*Locusta migratoria migratorioides*, *Schistocerca gregaria* and *Nomadacris septemfasciata*) that atmospheric humidity controlled almost all the life processes. He found that the rate of development of hoppers decreased when atmospheric humidity fell below the optimum, that the adults did not attain sexual maturity when atmospheric humidity was low and that unfavourable humidity adversely affected the fecundity of females. Further, it has been observed that the eggs of *Schistocerca gregaria* are not laid in dry soil and do not develop in a partially saturated atmosphere [Bodenheimer, 1929]. Thus, it would appear that practically every stage in the life-cycle of a locust is greatly influenced by moisture.

For experiments of the nature described in this paper abundant and easily available locust material is essential and such material can be procured only during a locust invasion. Although we are conscious of the incompleteness of the data presented, the possibilities of an approaching cycle of locust activities providing facilities for future work have prompted us to present the results obtained so far.

The investigation which forms the subject-matter of this paper was carried out under the Locust Research Scheme, financed by the Imperial Council of Agricultural Research, India. The Council's generosity is gratefully acknowledged.

II. Method employed and difficulties of procedure

Investigations concerning the influence of environmental moisture on the active stages of such insects, as feed on green leaves, are fraught with several serious handicaps. The presence in a small cage of green leaves which constantly transpire and of hoppers and adults, which give out from their bodies, along with expired air and faecal matter, a considerable amount of water, are factors which disturb the relative humidity persistently. This can be avoided to a certain extent by maintaining a current of air of the required relative humidity, but in cases where air currents of low humidity are used, the leaves dry up so quickly that without frequent replacements the insects are likely to remain underfed and the results vitiated. It will thus be observed that a constant disturbance of relative humidity and an underfeeding resulting from a quick drying up of food material under conditions of low humidity are two sources of error which develop in inverse proportion : adjust the one and the other develops.

In trying to maintain low humidity within reasonable range, Hamilton [1936] supplied food to his experimental locusts only once a day. In several cases, he even 'partially ' dried the leaves before presenting them to his insects.

He does not make any mention of the quantity of food eaten. As has been stated above, under such conditions the danger of underfeeding is evident. In Hamilton's experiments the death rate was very high. It must not be forgotten that the moisture content of the body of an insect is not solely dependent on atmospheric humidity, and that the physiological changes resulting from a deficiency of food and particularly of its water-content are liable to be confused with those arising directly from the effect of the dryness of the surrounding air.

Even in the case of eggs, there is considerable difficulty. On the one hand the eggs of the desert locust require an almost saturated atmosphere and a relatively high temperature for their development ; on the other hand, they are extremely susceptible to fungus and nematode attacks. High temperature and high humidity are exactly the conditions which are favourable for a vigorous growth of fungi and a quick multiplication of nematodes, and therefore it is often an extremely difficult matter to ensure successful hatching.

Water, soil and apparatus used in such experiments can be sterilised, but it is not as easy to deal with the eggs in a satisfactory manner. They are very delicate and fungicides are positively harmful to them. All that one can attempt to do is to wash the eggs thoroughly in sterilised distilled water. This method is however, not always an effective one ; even a few stray spores present may develop quickly under conditions of warmth and humidity and destroy the eggs. On account of these handicaps we have had numerous failures and a very large number of experiments had to be conducted to obtain the data presented in this paper.

III. Influence of atmospheric humidity on sexual maturation and longevity of adults

Sexual maturation

Temperature has a well-defined influence on the maturation of the sex-glands. For example, the pre-oviposition period of *Schistocerca gregaria* adults exposed to 36°C. is about three weeks and at 40°C. this period is reduced to about two weeks [Husain and Ahmad, 1936]. The relative humidity of the atmosphere has also been regarded as a factor influencing sexual maturation. Roubaud [1930] observed that *Schistocerca gregaria* adults kept in a moist atmosphere reached sexual maturity after three to four weeks only. On the other hand, sexual maturity was completely inhibited in adults placed in a dry atmosphere. At 35-40 per cent relative humidity and at temperature of 30°-40°C. the adults in his experiments lived for over ten months without ovipositing. He states :—

' J 'indiquerai tout d'abord qu'en captivite, les criquets maintenus en air humide (au moins a' 50 pour 100 d' etat hygrometrique) et a la chaleur peuvent parvenir rapidement et sans arret a la reproduction..................D' autre part, si l 'on soumet des criquets parvenus a l' etate adulte, mais encore sexuellement immatures, a des conditions de secheresse continue, plus ou moins comparable a celles des regions desertiques, on les voit supporter parfaitement bien ces influence................Les criquets maintenus en permanence a une haute temperature continue (30°C.—40°C.) mais avec un etat hygrometrique artificiellement abaisse a 35-40 pour 100, passent a une condition de latence tres caracteristique ; leur pigmentation n'evolus pas, l'activite alimentair, d' abord tres grande, se relentit lentement, tandis que l' evolution sexuelle se montre completement suspendue dans les deux sexes ; les insectes peuvent ainsi etre conserves pendant des mois en anhydrobiose sans parvenir a la maturite sexuelle. '

He thus concludes that sexual development is arrested by low atmospheric humidity. Unfortunately he does not mention anything about the food of the insects under experiments. Did he provide green leaves ? If so, were not the locusts able to get the required amount of moisture from their food ? In an atmosphere, where relative humidity is low, it is almost certain that the green leaves supplied as food would dry up very quickly. It seems, therefore, highly probable that in such experiments drying up of the food and the consequent underfeeding, resulting in deficiency of water in the tissues of the insect, are significant factors in inhibiting sexual maturation ; dryness of the air may perhaps be an indirect factor. Further it must be recognised that sexual maturity and oviposition are two distinct and independently controlled processes.

The latest contribution on the relation of atmospheric humidity to sexual maturity among locusts is that of Hamilton [1936]. He experimented with three species of locusts and arrived at the conclusion that in all these species, sexual maturity was retarded in the adults living in an atmosphere which contained either very low or very high relative humidity. Thus he found that for *Schistocerca gregaria* the lowest relative humidity at which sexual maturation occurred was 40 per cent at 90°F. and 45 per cent at 100°F. and that the optimum range of humidity was 40-75 per cent. Humidity of 80 per cent was considered by him to be the upper limit for sexual maturity. As has been shown above, it is doubtful if Hamilton was able to keep his insects properly fed and retardation in sexual development may have been the result of underfeeding. In the following account it is shown that when an adult desert locust is properly fed and gets the optimum amount of water through its food, the atmospheric humidity has no noticeable effect on the maturation process. All that matters is the presence of the requisite amount of moisture in the body, no matter how it is obtained and retained.

In one of our experiments, two pairs of fliers, obtained from hoppers bred under similar environmental conditions, were kept from the date of acquiring wings (20-21 March 1934) at 30°C. in 85 and 35 per cent relative humidity respectively. Fresh cabbage leaves were supplied four times daily. The female at 85 per cent relative humidity dropped the first batch of eggs on 6th April, i.e. after 17 days ; the female at 35 per cent relative humidity oviposited on 15th April, i.e. after 26 days. Thus sexual maturation was not inhibited but only delayed slightly by low atmospheric humidity.

In another experiment two lots of freshly hatched hoppers were bred crowded at 35°C. in 85 and 35 per cent relative humidities. On acquiring wings they were provided with moist sandy soil for oviposition, which was, however, covered over with thin parchment paper, and a layer of dry soil half an inch in thickness. Thus the moisture in the soil below could not disturb the relative humidity of the air above. The locusts were fed four times every day, as in the previous experiment. In 85 per cent relative humidity, a pair which had acquired wings on 9th September 1935, copulated and the female laid eggs on 24th September. Another pair, which was bred in 35 per cent relative humidity and which had acquired wings on 11th September copulated on 25th September. The female bored twice for oviposition on the same date. Finding the soil unsuitable for oviposition the eggs were withheld for six days and then dropped on the surface of the soil on 1st October. Thus the

preoviposition period was 15 days in the former case, and 14 days in the latter case, i.e., the adults in low and high humidities attained sexual maturity simultaneously.

It would appear from these experiments that in low atmospheric humidity sexual maturation of the desert locust is not significantly slackened and certainly not inhibited. We, therefore, believe that if the adults are provided with an ample supply of fresh food, e.g. if fed on green succulent leaves (preferably on a plant), the desert locust can attain sexual maturity however deficient in moisture the atmosphere may be.

Longevity of adults

To study the influence of saturated and moisture-deficient atmosphere on the longevity of freshly emerged adults the following experiment was conducted :

Two similar wire-gauze cages with moist soil at the bottom, were set up side by side. Along the four sides of one of the cages were hung curtains of cotton lint which were soaked with water and the lower free margins of which were kept immersed in a channel full of water. Thus the four sides of the cage were maintained moist. The water lost through evaporation from the surface of the cotton lint was replenished from the water provided in the channel. The top of the cage was left uncovered. In this manner the humidity in this cage was maintained at almost the saturation point. The other cage was left at room humidity which averaged 40 per cent. The longevity of the adults kept in these two cages is shown in Table I. All the adults were of the same age and were bred together before their transfer to their new environment.

TABLE I

Longevity of Schistocerca gregaria *adults in saturated and partially saturated atmospheres (temperature range : 26·6 to 36·6°C.)*

Serial No.	Date of transfer to cage	Saturated atmosphere (relative humidity—100 per cent)		Partially saturated atmosphere (average relative humidity 40 per cent)	
		Date of death	Longevity (days)	Date of death	Longevity (days)
1	15 July	17 July	2	30 July	15
2	,,	20 ,,	5	2 August	18
3	,,	21 ,,	6	28 ,,	44
4	,,	22 ,,	7	12 Sept.	59
5	,,	22 ,,	7	12 ,,	59
6	,,	30 ,,	15	23 ,,	70
7	17 July .	30 ,,	13	..	..
8	20 July .	5 August	16	..	..

It will be seen that the adult that lived longest in saturated atmosphere survived for 16 days only. Many of them lived for a much shorter period. On the other hand, in the cage kept at room humidity (average 40 per cent) the longevity reached a maximum of 70 days. Thus in an atmosphere containing moisture to saturation point the life-span of *Schistocerca gregaria* is cut short and the mortality percentage increases. It may be mentioned in this connection that the desert locust is extremely susceptible to bacterial and fungal diseases, and possibly this is one of the chief factors responsible for the short life of the locust in a saturated atmosphere. Roubaud [1933] also observed high mortality in humid atmosphere and very few deaths and longer life in dry atmosphere.

Hamilton [1936] found a gradual decrease in the length of life of *Schistocerca gregaria* with a rise in humidity. Eighty per cent humidity and above were found to be detrimental to the desert locust. These observations lead one to the conclusion that a comparatively less humid atmosphere suits the desert locust better, provided it is able to get the requisite water supply from its food. This is exactly the condition in the natural home of the desert locust. This view finds further support from the fact that the gregarious-phase locust flies far and wide into fertile areas but cannot survive and multiply for more than a generation or two in areas where humidity is higher than in its desert home. Thus while the fliers may reach the extreme eastern limits of India, their permanent home does not extend to the east and north beyond the Rajputana desert.

IV. Soil moisture and oviposition

Under natural conditions swarms of the adult locust oviposit in a great variety of soils, the one necessary condition being suitable soil moisture. In soils where moisture is deeper than usual eggs are laid at a comparatively greater depth than in soils where moisture is nearer the surface.

In a particular instance at Tala-gang (Attock district, Punjab) it was noticed that a swarm of the desert locust which was ready to lay eggs, settled on the sloping sandy bank of a stream of water. The soil moisture of the bank varied from saturation point, near the water edge of the stream, to almost dry sand at the top of the bank. The locust swarm restricted its egg-laying activity to a longitudinal strip of land a few feet broad and running parallel to the stream. For oviposition the soil next to the stream which was full of water, as well as the dry or almost dry soil farthest from the running water was avoided. In this connection, Gough [1916] states, ' The females appear to be very careful in the selection of the best site in the neighbourhood for depositing their eggs ; and yet the choice varies immensely in different places. Absolutely dry sand and wet mud are never used if more suitable positions are available. Banks of canals and drains or irrigation channels in the fields are often selected. In such places the eggs are in a definite zone, not too close to the water (at the time of laying) nor too high above it, as to cause the place to be too dry '.

Our experience in the laboratory confirms these observations. Fully mature females placed in cages provided with dry sandy soil bored at several places but did not oviposit. They withheld their eggs as long as was physically

possible for them to do so and finally dropped the eggs on the surface of the soil. Where soil was watered at this stage the eggs were readily laid in the soil in the normal manner.

Definite experiments were conducted to analyse this behaviour. An oviposition cage was fitted with glass tubes (3 cm. bore and 15 cm. long) which were filled with dry and moist sand up to different depths and in different orders. In order to prevent moisture of the wet soil running into the dry soil, the two layers were separated by thin water-proof paper. Mature females were introduced in these cages. The results are presented in Table II.

TABLE II

Influence of soil-moisture on oviposition.

Upper layer of soil		Lower layer of soil		Total depth of bore in which eggs were laid (cm.)	Remarks
Nature	Depth (cm.)	Naure	Depth (cm.)		
Moist	7·5	Dry	7·5	8·0	Eggs laid
,,	8·0	,,	7·0	8·0	,, ,,
,,	6·5	,,	8·5	6·5	,, ,,
,,	5·5	,,	9·5	..	No eggs laid; bored into dry soil
,,	5·0	,,	10·0	..	,, ,,
,,	4·0	,,	11·0	..	,, ,,
,,	3·5	,,	11·5	..	,, ,,
,,	2·0	,,	13·0	..	,, ,,
Dry	9·5	Moist	5·5	8·0	Eggs laid
,,	9·0	,,	6·0	9·5	,, ,,
,,	8·0	,,	7·0	9·8	,, ,,
,,	8·0	,,	7·0	8·5	,, ,,
,,	4·0	,,	11·0	7·5	,, ,,
,,	3·0	,,	12·0	7·0	,, ,,
,,	2·0	,,	13·0	6·8	,, ,,

It will be noticed that when the layer of moist soil which is always sought for oviposition, lay below the dry soil the females bored through the dry layer, if it was not too deep, pierced the paper and getting into the moist soil oviposited there. On the other hand, when the top layer was moist, the female, in order to avoid the dry soil below, laid eggs at a much shorter depth than normal. When the top layer of moist soil was much too thin the eggs were not laid there, it being physically impossible for the locust to lay eggs at a depth shorter than a certain minimum. Normally the abdomen is thrust into soil up to the III segment or so before the eggs are deposited. When the top layer is of dry soil and is too deep for the abdomen of the female to bore through, she desists from oviposition.

It has been commonly observed that swarms of locust do not settle and lay eggs in a field if it is flooded with water. What is it that prevents the locust from doing so ? In an experiment ripe females were kept in a cage in which water was kept standing. They did not lay eggs as long as the water was there, but when the surface water was drained off the eggs were laid in the otherwise waterlogged soil. In another experiment females were made to oviposit in water. A breeding cage was fitted with test-tubes, each of which was filled with water except for the upper two inches which contained soil supported by waterproof paper partition which was fixed to the tube by means of wax. The female bored through the two inches of sand and pushed her abdomen into the water and dropped eggs and deposited froth. This shows that a female is not incapable of laying eggs in water but in a flooded field she cannot do so because perhaps the conditions there do not allow her to get the requisite anchorage to bore a hole. It must be made clear that in these experiments the locusts were made to lay eggs in somewhat unfavourable situations.

While making observations on the above-mentioned female as she laid eggs in water, it was interesting to note her rather extraordinary behaviour. Normally, as a female oviposits she contracts her abdomen a little to allow the egg to be deposited. The female which was ovipositing in water had no such necessity. Each egg that was deposited dropped down at the bottom. Thus the female continued to lay the cluster without contracting her expanded abdomen. Finally, the female started withdrawing her abdomen and depositing frothy matter.

V. Influence of relative humidity of air and soil-moisture on incubation

Influence of relative humidity of air

Freshly laid eggs were removed and placed on cotton lint in glass tubes kept at constant relative humidities of 60, 80, 90, and 100 per cent and constant temperatures of 25, 33, 35 and 37°C. In a second series, batches of eggs which had completed about one-third development were placed in 80, 90 and 100 per cent relative humidities at room temperature (28°-30°C.). Results are set out in Table III.

It will be seen that at 90 per cent relative humidity and below, fresh eggs could not complete their development. With cent per cent relative humidity the incubation period was 11 days at 37°C., 11 to 12 days at 35°C., 12 days at 33°C., and a little less than 32 days at 25°C. The eggs which had

TABLE III

Incubation period at different temperatures and relative humidities

Temp. (°C.)	Relative humidity (per cent)	Date of oviposition (1931)	Date of hatching		Incubation period (days)	Remarks
			Tube No. 1	Tube No. 2		
			A. Freshly laid eggs			
37	100	21 Aug.	1 Sept.	1 Sept.	11	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
35	100	do.	2 Sept.	1 Sept.	12	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
33	100	do.	2 Sept.	2 Sept.	12	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
25	100	do.	22 Sept.	22 Sept.	about 32	On 22 Sept. found hatched and dead: one living
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
			B. Eggs which had completed 1/3 of their development			
28–37	100	do.	4 Sept.	..	15	3 out of 5 hatched
,,	90	20 Aug.	4 Sept.	..	15	1 out of 5 hatched
,,	80	do.	6 Sept.	..	17	do.

completed one-third of their development took 15 days to complete the remaining two-thirds of the embryonic development in 90 as well as 100 per cent relative humidities at room temperature (28°—37°C.), but those kept in 80 per cent relative humidity hatched after 17 days, i.e. two days later than the eggs kept at the same temperature but incubated under optimum moisture conditions. Bodenheimer [1929] performed similar experiments on eggs which had completed one-third or two-thirds development. He also arrived at the conclusion that the eggs exposed to a partially saturated atmosphere, at a later stage of development, were able to complete their development.

Thus it may be concluded that freshly laid eggs can develop only in saturated atmosphere, a lower relative humidity being fatal for them. Partially developed eggs can complete their development in an atmosphere of lower relative humidity but the rate of development is considerably retarded.

Influence of deficient soil moisture

In *Locustana pardalina*, which undergoes a long diapause in the egg stage, Faure [1932] succeeded in hatching eggs which lay dormant in dry soil for 37 months, and according to Lounsbury [1915] they could be kept in a state of suspended animation for three and a half years. *Locustana pardalina* is characterised by the existence of a diapause in the egg stage and Faure mentions that the normal suspension of development takes place in spite of temperature and moisture being favourable for development. On the other hand *Schistocerca gregaria* has no egg-diapause, i.e. the development of the embryo is continuous provided the temperature and soil-moisture are favourable.

Statements have often been made to the effect that eggs of *Schistocerca gregaria* also remain undeveloped for a long time, and according to some for years, if kept under relatively dry conditions. Further that such eggs resume embryonic development when sufficient moisture becomes available to them. King [1921] mentions this possibility for *Schistocerca gregaria* but deplores lack of evidence. He suggests the possibility of oviposition occurring sometimes in dry earth and the eggs remaining unhatched until rain falls and provides them with the requisite moisture. This prolongation of the egg-stage has been reported to occur under natural conditions also. If this is so, it is evident that low temperature cannot be the determining factor. The threshold of development of the eggs of the Desert Locust is about 18°C. and in no region of the breeding area of the Desert Locust does a temperature of 18°C. or less prevail for a long period of time. Therefore it is likely that in such cases moisture is the controlling factor. No experimental evidence was available to support these statements in the case of *Schistocerca gregaria*. Experiments were designed to discover the influence of deficiency of moisture in soil on the development of eggs. The difficulties of these experiments have been pointed out. In what follows, results of successful experiments have been given. Four experiments were carried out with sandy soil and one each with loam, clay-loam and clay soil. In experiments 1 and 2 the sand used was dried in an oven at 60°C. In order to obtain maximum hygroscopic moisture, this sand was then kept in a dish in a desiccator with cent per cent relative humidity for two days and was occasionally stirred. To the soil, which had absorbed maximum hygroscopic moisture a measured quantity of water was added (Table IV) and the soil thoroughly mixed. Freshly laid

eggs were removed from the soil of the oviposition cages and placed about ½ inch below the soil of known moisture-contents in each dish. The dishes were then returned to the desiccator in which the atmosphere was always maintained, saturated with moisture, at room temperature. In all the dishes, including those that contained sand with maximum hygroscopic moisture, hatching took place without further moistening of the soil. Evidently the eggs in sand were in equilibrium with a fully saturated atmosphere and there was free water of condensation in the soil available to the eggs.

In experiment 3, (Table IV) one batch of eggs was placed in air-dry sand (dish *a*), i.e. in sand containing moisture below the maximum hygroscopic limit. The second batch was placed in moist sand to serve as control (dish *b*). After placing the eggs the mouths of both the dishes were sealed with wax and wax-paper. In another experiment (4) one batch of eggs was similarly sealed in sand containing only hygroscopic moisture in equilibrium with 80 per cent relative humidity (dish *a*) and another in moist soil to serve as control (dish *b*). On 14 May 1934 and 21 May 1934 when the respective control eggs had hatched, some water was added to the soil of the other dishes in which no hatching had taken place. The eggs in these dishes hatched on 25 May and 31 May respectively, i.e. 10 to 11 days after moistening.

Experiments 5, 6, and 7 were conducted on the same lines as experiments 1 and 2 except that the soil used was loam in experiment 5, clay loam in experiment 6 and clay in experiment 7. The eggs hatched in all the dishes in which the soil contained a higher percentage of moisture, while in the case of dishes containing low soil-moisture, namely dish *e* in experiment 5 and *b* and *c* in experiment 6, no hatching took place until the soil was moistened subsequently. It will be noticed that several of these dishes contained soil having a much higher percentage of water than the maximum hygroscopic moisture. The results of these experiments are given in Table IV.

TABLE IV

Influence of soil-moisture on the development of eggs (1934)

Experiment No.	Reference No.	Soil	Dish No.	Percentage of moisture added	Date of oviposition	Date of moistening	Date of hatching	Incubation period (days)	Temperature during experiment (°C.)	
									Average maximum	Average minimum
1	R22	Sandy	a	Saturated	4 Aug.	...	16 Aug.	12	34	33
	,,	,,	b	8·4	do.	...	17 ,,	13	,,	,,
	,,	,,	c	4·2	do.	...	18 ,,	14	,,	,,
	,,	,,	d	Max. hyg.	do.	...	21 ,,	17	,,	,,
2	P30	,,	a	4·6	4 Sept.	...	17 Sept.	13	,,	31·2

TABLE IV—*contd.*

Experiment No.	Reference No.	Soil	Dish No.	Percentage of moisture added	Date of oviposition	Date of moistening	Date of hatching	Incubation period (days)	Temperature during experiment (°C) Average maximum	Average minimum
	P30	Sandy	b	4·6	4 Sept.	...	17 Sept.	13	34	31·2
	,,	,,	c	2·25	do.	...	19 Sept.	15	,,	,,
	,,	,,	d	2·25	do.	...	19-21 ,,	15–17	,,	,,
	,,	,,	e	Max. hyg.	do.	...	27-29 ,,	23–25	33·6	29
3	L456	,,	a	Air dry	27 April	14 May	25 May	28	30	Constant
	,,	,,	b	Control	do.	...	14 ,,	17	...	,,
4	L452	,,	a	Hyg. at 80 per cent R. H.	8 May	21 May	31 ,,	23	35	,,
	,,	,,	b	Control	do.	...	21 May	13	...	,,
5	Q16	Loam	a	30	18 July	...	31 July	13	36·1	33·0
	,,	,,	b	20	do.	...	do.	,,	,,	,,
	,,	,,	c	20	do.	...	do.	,,	,,	,,
	,,	,,	d	5	do.	...	3–4 Aug.	16–17	36·0	,,
	,,	,,	e	Max. hyg.	do.	...	6 Sept.	50	34·9	31·8
6	P30	Clay loam	a	13·3	4 Sept.	Attacked by fungus				
	,,	,,	b	6·6	do.	14 Nov.	24 Nov.	81	28·4	24·1
	,,	,,	c	6·6	do.	do.	do.	81	,,	,,
	,,	,,	d	Max. hyg.	do.	10 Nov.	Attacked by fungus			
7	Q14	Clay	a	18·7	7 Aug.	...	19 Aug.	12	34	33
	,,	,,	b	9·8	do.	...	21 Aug.	14	,,	33
	,,	,,	c	5·3	do.	21 Aug.	6 Sept.	30	32·5	31·7
	,,	,,	d	3·2	do.	do.	do.	30	,,	31·7
	,,	,,	e	Max. hyg.	do.	5 Nov.	Attacked by fungus			

Conclusions.—From Table IV it is evident that in sandy soil, containing maximum hygroscopic moisture and exposed to fully saturated atmosphere, the eggs of the desert locust were able to complete their development, although the incubation period was longer by five days as compared to the control eggs kept at optimum soil-moisture. Thus a comparative deficiency of moisture in soil resulted in a corresponding prolongation of the incubation period. When, however, the eggs were placed in soil more deficient in moisture, for example in air-dry sandy soil, i.e. in sand containing less than the maximum hygroscopic moisture, the development of eggs was arrested, and recommenced only when the soil was subsequently sufficiently moistened. Thus, in experiment 3, whilst the eggs in the control hatched after an incubation period of 17 days, those in air-dry sand had to be provided with more moisture to complete their development. These eggs hatched 11 days after the moisture was added. The incubation period at the temperature at which this experiment was conducted being 17 days, and the incubation period after the

subsequent addition of water being 11 days, it may be correct to assume that the development to the extent of six days of incubation at this particular temperature had taken place before the eggs were moistened. One may assume that the water required for this extent of development was available in the eggs. Similarly in experiment 4, eggs in moist sandy soil hatched after 13 days, while those in sandy soil, with hygroscopic moisture in equilibrium with 80 per cent relative humidity, remained unhatched and completed their development ten days after the soil was moistened subsequently. Thus during the 13 days that the eggs were in dry soil at 35°C. they had undergone development equal to three days' incubation under optimum conditions of moisture.

These experiments are of particular interest, because the soil and the eggs were kept in dishes the mouths of which had been sealed and, therefore, the humidity and soil-moisture were uniform throughout the experiment.

In the case of loam soil even when it contained maximum hygroscopic moisture (dish *e*, experiment 5) the development of eggs was completely arrested. The control eggs hatched after 13 days (dishes *a*, *b* and *c*) but these eggs (dish *e*) were unhatched after an incubation period of 34 days, when on 21 August they were moistened. They hatched on 6 September, i.e. 16* days after the date of moistening. Equally interesting is the case of dish *d* (experiment 5). Eggs were kept in loam soil to which, in addition to its maximum hygroscopic moisture, 5 per cent water by weight had been added. Hatching took place on 3 and 4 August, i.e. the incubation period was 15 to 16 days as against 13 days in loam soil to which in addition to the maximum hygroscopic moisture 10 per cent or more water (dishes *a*, *b* and *c*) had been provided from the very beginning. This prolongation of the incubation period by a few days shows that in loam soil 5 per cent water plus maximum hygroscopic moisture is a little less than the amount of moisture required for normal incubation. A comparison of the results of this experiment with those of experiments 1 to 4 shows that the quantity of water available for absorption by the eggs from soils of different nature varies although the various soils may contain the same percentage of water.

In clay-loam (experiment 6, dish *d*) and in clay (experiment 7, dish *e*) containing maximum hygroscopic moisture the eggs remained unhatched up to 67 days and 90 days respectively by the end of which they were found on examination to be healthy. On addition of water at the end of this period, however, they contracted fungus infection and none of the eggs could complete its development. In clay-loam (dishes *b* and *c*, experiment 6) to which, after the adsorption of maximum hygroscopic moisture, 6·6 per cent water had been added, the eggs laid on 4 September remained, so to say, dormant till 14 November, the date on which water was added to the soil. They hatched on 24 November, i.e. 81 days after the date of oviposition. In our experiments this is the maximum length of time over which the incubation period of the eggs of the desert locust was extended without loss of viability by providing conditions of moisture-deficiency in soil. Similarly in the case of clay (experiment 7) eggs placed in

*Sixteen days is about the normal incubation period at the temperature to which the eggs were subjected (Table IV).

dishes *c* and *d* (water 5·3 per cent and 3·2 per cent plus maximum hygroscopic moisture) remained unhatched up to 21 August, when moisture was added. They hatched on 6 September, i.e. 30 days after oviposition, the normal incubation period at the temperature at which this experiment was conducted being 12 days only.

The behaviour of soils of different texture is very interesting. In sandy soil eggs were able to complete their development when the soil contained only maximum hygroscopic moisture and the atmosphere to which it was exposed was kept saturated ; in heavier types of soils a percentage of moisture greater than the hygroscopic maximum was necessary for the complete development of eggs.

Under conditions of deficient soil-moisture, i.e. when the soil-moisture fell below a certain minimum percentage, varying with the texture of the soil, the embryonic development was completely arrested and recommenced only when the percentage of moisture was raised. The amount of moisture required increased with the heaviness of the soil.

These conclusions are obviously of very great importance. It has been established that in *Schistocerca gregaria* embryonic development is arrested by insufficiency of available moisture. Thus it is clear that, should dry conditions prevail in nature over a long period, it is not unlikely that eggs will remain dormant during the prolonged period of drought and hatch out only after precipitation.

Discussion.—The condition of the soil in which eggs were placed may be described thus. Soil is essentially a mass of loose particles of solid matter with a film of water surrounding them. The interspaces are thus occupied by water and air. The size of the interspaces depends on the texture of the soil. An egg placed in a soil will have a portion of its surface in contact with the soil particles and, therefore, in contact with the water fi m ; and a portion will also be exposed to the atmosphere in the soil and perhaps a film of water may get deposited upon the surface of the egg.

Moist soil exposed to a partially saturated atmosphere loses its moisture to a certain degree, varying with the texture of the soil, but this water is firmly held by the soil particles. It is well known that the remaining moisture, which is in equilibrium with the air and is known as hygroscopic moisture, cannot be utilized by plants. Wilting begins before the water-content of the soil falls below the hygroscopic limit because soils will rather retain such water than give it up to the plant. Nor can such water move from particle to particle [Hall, 1918]. The eggs of locusts placed in the soil can be likened to root hairs of plants. They would be drawing water from the film held round the soil particles. The force with which the film of water is held by the particles of soil depends upon the size and nature of the particles.

In most of the experiments described above the soil was exposed to a saturated atmosphere during the entire period of incubation. Since the air in a soil kept in an atmosphere of cent per cent relative humidity would also be saturated, the case would be similar with eggs exposed to a fully saturated atmosphere. If so, why did some of the eggs exposed to a saturated atmosphere in some of these experiments complete their development, while others did not ?

It seems to us that for normal development an egg must not only be exposed to a fully saturated atmosphere to prevent the loss of its own moisture,

but must also come in direct contact with water which it has to absorb. The fact that during the course of development eggs increase in weight supports this contention. In a saturated atmosphere even a small fall of temperature would result in a condensation of water in the soil. Such moisture being above the maximum hygroscopic limit may be easily available to eggs in sandy soils where on account of the comparatively bigger size of the sand particles it is rather loosely held, but in the case of heavy soils may be too firmly held to be easily absorbed by the eggs. The development of eggs would be affected accordingly. It seems very likely that, in cases where eggs hatched in a saturated atmosphere and in light soils having only the maximum hygroscopic moisture, it was this accidental precipitated water of condensation that provided the necessary moisture for embryonic development.

VI. Influence of saturated air on intermediate moult

It has been stated [Uvarov, 1928] that freshly emerging larvae cannot shed their intermediate moult in an atmosphere saturated with water vapour. It is argued that in moist air the chitin becomes too elastic and is difficult to burst.

Experiments were started to verify this statement. Fully incubated eggs were obtained from a field where they had been laid by a swarm, and transferred to a desiccator with cent per cent relative humidity on 15 August 1931. All the eggs hatched out on 16 and 17 August and the larvae shed their intermediate moults normally. A number of similar other experiments were performed with the same results. The question is of great practical significance because it may mean that after showers of rain, when the soil is giving out moisture and the air near the soil surface is fully saturated, the intermediate moult would not take place in nature. This, however, is contra-indicated by numerous actual observations.

VII. Influence of atmospheric humidity on hopper development

Three experiments were performed to determine the influence of relative humidity on the duration of the hopper stages of the desert locust. Experiment 1 was conducted at room temperature (average maximum 30·9°C., average minimum 27·1°C.) and at 45, 60, 80 and 100 per cent relative humidities, which were maintained by means of super-saturated solutions of salts. The hoppers were reared singly in Petri-dishes in the manner described by Zwölfer [1932]. For food they were provided with cabbage leaves which were renewed four times each day, when regular observation were recorded as to the stage of the hoppers. The frequent changing of the leaves however, caused some fluctuation in the percentage of humidity.

Experiment 2 was conducted on the same lines as experiment 1 except that the hoppers were reared crowded and at a constant temperature of 36°C. Only two humidities (85 per cent and 35 per cent) were tried.

In experiment 3, in order to avoid fluctuations of humidity, no leaves were placed with the hoppers. Four times each day, i.e. at 7, 12, 17 and 21 hours, the hoppers were transferred from their air-conditioned chambers to cages provided with fresh cabbage leaves and kept in a thermostat maintained at the corresponding temperature. An interval of an hour was

allowed for feeding, after which the hoppers were replaced in their respective chambers. During the feeding period the hoppers remained at an unknown but presumably higher humidity. The hoppers in this experiment were reared singly at a temperature of 36°C.

In experiment 1 (Table V) the average duration of the last two hopper stages at 45, 60 and 80 per cent relative humidities is the same, i.e. about 19 days. The one hopper that reached the adult stage at cent per cent relative humidity had a longer duration for the two stages, namely about 26 days. This insect was sickly throughout and for this reason it is not desirable to draw any inference. Saturated atmosphere, as has been shown earlier, causes disease among the adult locusts and it is probably equally unsuitable for the hopper stages of the desert locust.

The duration in experiment 2 also is the same for low (35 per cent) and high (85 per cent) relative humidities, i.e. on the average the hopper stage lasted 22 days in both the humidities.

In experiment 3 (Table V) a little lower relative humidity (23 per cent) was tried. It will be seen that the duration of the hopper stage in low humidity (23 per cent), which is lower than the one tried in experiments 1 and 2, is a little longer than in high humidity (80 per cent). Also, that the total average duration in both the humidities is longer than the normal duration at the temperature at which this experiment was conducted. This point will be referred to again.

Table V

Rate of growth of hoppers at different relative humidities

Expt. No.	Temp. (°C.)	Relative humidity	Duration of different stages (days)							No. of hoppers	Remarks
			I	II	III(*a*)	III(*b*)	IV	V	Total		
1	Average max. 30·9	100	...	...	...	...	9·5	17·3	26·8	1	The hoppers were reared singly
		80	...	...	...	...	8·0	11·4	19·4	7	
	Average min. 27·1	60	...	...	...	...	7·9	11·8	13·7	7	
		45	...	...	...	...	7·8	11·2	19·2	7	
2	36	85	3	4	3	...	4	8	22	26	The hoppers were reared crowded
	36	35	3	4	3	...	4	8	22	12	
3	36	80	...	...	6	7	5	10	28	1	Female
			...	...	5	6	6	10	27	1	Male
			...	...	6	7	6	10	29	1	Male
			...	...	6	6	7	10	29	1	Hoppers were reared singly
	36	23	...	...	6	6	7	10	29	1	Female
			...	...	9	6	6	10	31	1	Male
			...	...	...	14	7	9	30	1	Female
			...	...	6	...	7	9	22	1	Male
			...	...	...	13	7	9	29	1	Male
			...	...	...	13	9	9	31	1	Female
			...	...	7	...	5	12	24	1	Female
			...	...	...	13	7	10	30	1	Male
			...	...	6	7	7	11	31	1	Male

Key [1936] has studied the effect of humidities on the length of hopper stages in *Locusta migratoria migratorioides*. He selected 99-100 per cent relative humidity on the one side and 5-10 per cent on the other and concluded that with the decrease of relative humidity the durations of the stages increase. For ready reference, his figures are given below.

Length of stages in Locusta migratoria migratorioides (*days*)

Instar	High humidity (99-100 per cent)	Low humidity 5-10 per cent
I	6·8	12
II	6·4	12·0
III	5·9	8·6
IV	7·4	9·7
V	11·5	14·5

Attention may be drawn to the fact that these hoppers were supplied with 'small quantities of food once a day'.

On the other hand, Hamilton [1936] finds that *L. migratoria* has an optimum at about 60 per cent relative humidity at 90°-100°F. and that the duration increases as the relative humidity rises above or falls below this optimum. In the case of *Schistocerca gregaria* he finds that the optimum relative humidity at 90°F. is about 60 per cent and at 100°F. about 70 per cent. As in *L. migratoria*, so also in *S. gregaria* he finds that the duration of the hopper stages increases as the relative humidity diverges from this optimum. In his endeavour to avoid disturbing the humidity, Hamilton supplied food (grass or young wheat) only once a day to each cage.

In our experiments 1 and 2, where constant supply of green food was maintained, the duration of the hopper stages is about the same as is normal at the temperatures at which these experiments were conducted. While in experiment 3 where the insects had no food for 20 hours each day the duration of hopper stages at both the humidities is much longer than what it normally is at 36°C., the temperature at which this experiment was conducted. We thus conclude that this increase in the duration of the hopper stage is the result of under-feeding. In this experiment the increase is more pronounced in the case of hoppers at lower humidity. Possibly the greater loss of water from the body at the lower humidity is not made good during the four hours of feeding. Similarly, there must have been under-feeding in the case of hoppers in experiments of Key and Hamilton. The food must have dried up quicker at low relative humidity, resulting in greater under-feeding and prolongation of the hopper stages with decrease of amount of moisture in the air.

These experiments prove beyond doubt that the larval and imaginal development of *Schistocerca gregaria* is not appreciably affected by variations in relative humidity, provided the insect is able to get plenty of fresh food. Low humidity, prolongs the duration of hopper stage only indirectly, namely by making the food less congenial to the insect.

Summary

The sexual development of the adults is not inhibited by dry atmosphere if fresh food is available. Eggs are laid in soil sufficiently moist. Moisture has a marked influence on the incubation of *Schistocerca gregaria* eggs. Eggs

are not able to complete their development in a partially saturated atmosphere. Even with suitable temperatures the development may be arrested if the soil-moisture is deficient. In this way eggs were experimentally kept dormant for a period of 81 days under conditions of temperature at which normal incubation is only about three weeks. They recommenced development after moistening. These observations show the possibility of eggs remaining dormant for a long time in nature and hatching after rain.

The influence of low atmospheric humidity on hopper development is insignificant, provided a supply of fresh food, which is the normal source of intake of water, is available. A completely saturated atmosphere is, however, decidedly detrimental ; it slackens larval development, shortens the adult life and increases mortality.

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BIONOMICS AND CONTROL OF THE FIG-TREE BORER, *BATOCERA RUFOMACULATA* DE GEER (COLEOPTERA : LAMIIDAE)

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(With Plate XLIV)

I. Introductory

BATOCERA RUFOMACULATA De Geer is a very serious pest of fig trees, so much so that in certain localities fig growing is impossible, becuase of the ravages of this insect. For instance, in the Experimental Fruit Orchard at Lyallpur, 53 fig trees were planted in 1925 and by 1932 only three had survived the attacks of this borer.

Stebbing [1917] made some preliminary observations on this pest, but did not study its complete life-history. Beeson [1919] studied the food plants of this insect. Gardner [1927] described the mature larva and pupa. The observations made by us during the last few years are presented in this paper.

We acknowledge with thanks the information supplied by the Forest Entomologist, Dehra Dun, from his unpublished records, and we are further grateful to him for his permission to make use of it.

II. Synonomy [From Aurivillius, *Col. Cat.*, **73** : 127]

Batocera rufomaculata, De Geer, *Mem. Ins.*, *V*, 1775, p. 107. —Retzius, De Geer. *Gen. Spec.*, 1783, p. 138	India, Ceylon
———*cruentata*, Gmel. in L. *Syst. Nat.* ed. 13, I, 4, 1790, p. 1863	Madagascar
———*rubiginosa*, Voet, *Cat. Col.*, II, 1778, p. 34, t. 13, f. 53	Mauritius, Bourbon. German East Africa
———*rubra*, Maxwell-Lefroy, *Ind. Ins. Life*, 1909, p. 375, f. 245, 247.—Pierce, *Dangerous Ins.*, 1917, p. 103, f. 21.	
———*rubus*, Schröter, *Abhandl.*, I, 1776, p. 333, t. 2, f. 2.	
———*rubus*, Stebbing, *A Note on the Duki Fig Borer*, *Bull.* 10, 1907	
———*rubus*, var. *andamana*, Thoms., *Revue Zool.* (3) VI, 1878, p. 54.—Kriesche, *Revis*, p. 147	Andaman
———*rubus*, ab. *chlorinda*, Thoms., *Archives Ent.* I, 1857, p. 171 ; Monogr., p. 80.—Rits. *Notes Leyden Mus.* IX, 1887, p. 220.	East Indies

Batocera rubus, var. *diana*, Nonfr. *Deutsche Ent. Zeitschr.* 1891, p. 276.—Kriesche, *Revis*, p. 147 . .	Tibet
———*rubus*, ab. *polli* Gah. *Ann. Mag. Nat. Hist.* (6) V, 1890, p. 55, t. 7, f. 2	Ceylon
———*rubus*, ab. *thysbe*, Thoms. *Revue Zool.* (3) VI, 1878, p. 52	Cochin China

III. Distribution

World distribution

B. rufomaculata is widely distributed in India, Ceylon, Malaya and East Africa. According to Duport [1914] it is present in the Far East and infests *Hevea* sp. Hutson [1920] has recorded it as a serious pest of *Artocarpus integrifolia* (jak tree) in Ceylon. It also occurs in Mauritius, Madagascar and Reunion. It got introduced into Torlota in 1914 and attacked and killed nearly all the native fig trees [Report of the Department of Agriculture, British Virgin Islands, 1920].

Distribution in India

According to Lefroy [1909] *B. rufomaculata* is found throughout the Indian plains. This has been confirmed by subsequent workers. Stebbing [1914] records it from Duki, Loralai (Baluchistan) (Col. C. A. Kemball) and Fort Sandeman (Major Roome *et mihi*). Fletcher [1914] found it throughout Southern India. Beeson [1919] has recorded it from Gorakhpur division of the United Provinces and Ramakrishna Ayyar [1923] from the Madras Presidency.

Distribution in the Punjab

It is probably distributed all over the province, but has, so far, been definitely recorded as a serious pest from Lyallpur, Sargodha, Hoshiarpur and the Kulu valley (on wild fig trees).

IV. Food plants

B. rufomaculata has a wide range of host plants belonging to 11 natural orders. A list of the host plants is given below :—

Food plants of Batocera rufomaculata *De Geer*

Food plant	Natural order	Country	Reference
Shorea robusta . . .	Dipterocarpaceæ	India . .	Unpublished records of the Forest Entomologist, Dehra Dun
Bombax malabaricum .	Malvaceæ .	,, . .	Beeson
Eriodendron anfractuosum .	,, .	Mauritius .	*Bull. Imp. Ist.*, XXIV, No. 1, 1926

Food plant	Natural order	Country	Reference
Sterculia colorata	Sterculiaceæ	India	Unpublished records of the Forest Entomologist, Dehra Dun
S. villosa	,,	,,	
Garuga pinnata	Burseraceæ	,,	
Buchanania latifolia	Anacardiceæ	,,	
Lannea grandis	,,	,,	
Mangifera indica	,,	Mauritius Virgin Islands	Wilson, Emmerz and Gebert
Odina wodier	,,	India	,, ,, ,,
Semecarpus anacardium	,,	,,	Unpublished records of the Forest Entomologist, Dehra Dun
Spondias magifera	,,	,,	
Moringa pterygosperma	Moringaceæ	,,	Beeson
Albizzia lebbek	Leguminosæ	,,	,,
Erythrina indica	,,	,,	Beeson & Fletcher
Barringtonia acutangula	Myrtaceæ	,,	Unpublished records of the Forest Entomologist, Dehra Dun
Adina cordifolia	Rubiaceæ	,,	
Hevea braziliensis	Euphorbiaceæ	,,	Beeson; Ayyar
Hevea sp.	,,	Far East	Duport
Artocarpus integrifolia	Urticaceæ	Ceylon	Hutson
A. incisa	,,	Ceylon	Hutson
Broussonetia papyrifera	,,	India	Unpublished records of the Forest Entomologist, Dehra Dun
Ficus asperrima	,,	,,	,,
F. bengalensis	,,	,,	,,
F. carica	,,	,,	Beeson
F. elastica	,,	,,	Wilson
F. glomerata	,,	,,	Beeson

Food plant	Natural order	Country	References
F. infectoria . . .	Urticaceæ	India	Unpublished records of the Forest Entomologist, Dehra Dun
F. pedunculata . .	,,	,,	Wilson
F. religiosa . . .	,,	,,	Unpublished records of the Forest Entomologist, Dehra Dun
F. tjakela . . .	,,	,,	
Morus indica . . .	,,	,,	
Almost any plant having a thick bark or possessing laticiferous vessles.	..	Virgin Islands	(Notes Insect pests Agric. Dept. Virgin Islands, Barbados. 1918-19)

In the Punjab it is the most destructive pest of fig trees and also attacks mango trees. Besides, it has been observed attacking apple trees (grown experimentally) at Lyallpur.

V. Description of the various stages

Stebbing [1907; 1914] has given a brief description of the full-grown grub and beetle. Gardner [1927] has given a fuller description of the full-grown grub and pupa.

Egg (*Plate XLIV, figs. 1-2*).—Oval, 5·5-6·8 mm. long and 1·8-2·3 mm. in diameter, chorion thick and leathery, surface very faintly marked with hexagonal impressions, colour dirty-white, micropylar end thicker with a circular depression bounded by a thick lip and surrounded by a brownish area.

Freshly-hatched grub (*Plate XLIV, figs. 3-7*).—Creamy-white in colour with head dark brown; slender, thickest in the thoracic region, gradually tapering towards the anal end, 8·4 mm. long and 2·7 mm. broad at the thorax; head 1·8 mm. long, 1·9 mm. broad; mandibles strong and dark in colour; labrum, labium and maxillæ covered with sharp bristles. Antennæ very minute, segmented, tipped with sensory papillæ. Pronotum with numerous strongly chitinised flattened denticles. Behind each spiracle there is a thick spine, directed backwards. Spiracles very characteristic, each possessing bilobed protuberance (in the later instars this structure disappears). Body covered all over with numerous minute spines.

Full-grown grub (*Plate XLIV, figs. 8-11*).—About 3 in. long, 0·8 in. wide at the thorax; body creamy-white, tapering towards the 8th segment and cylindrical further on; head dark brown with short antennæ; prothorax burnt-umber; thoracic legs rudimentary, extremely small, encircled with sharp minute bristles. Minute tubercles and denticles arranged on all the thoracic and abdominal segments. Spiracles nine on each side; just like oval pits of burnt-umber colour.

BATOCERA RUFOMACULATA DE GEER

FIG. 1. Egg

FIG. 2. Micropylar end of the egg (highly magnified)

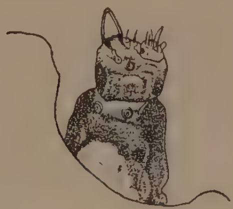

FIG. 3. Antenna of freshly-hatched grub

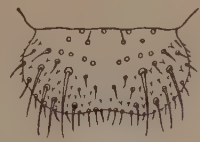

FIG. 4. Labrum of freshly-hatched grub

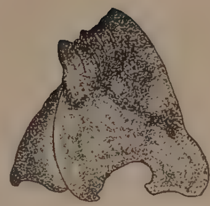

FIG. 5. Mandible of freshly-hatched grub

FIG. 6. Maxillae and labium of freshly-hatched grub

FIG. 7. Spiracle of freshly hatched grub, with spine and bilobed process

FIG. 8. Grubs of different stages—2nd instar to full-grown (For size see description)

FIG. 9. Spiracle of a full-grown grub

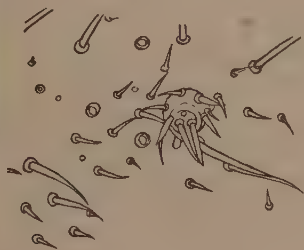

FIG. 10. Region of the meso-leg of a full-grown grub showing a rudimentary leg

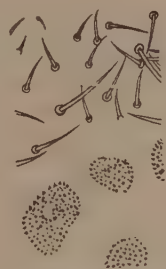

FIG. 11. Denticles and minute tubercles on ventral surface of the 9th segment of full-grown grub

FIG. 12. Pupa (side view)

FIG. 13. Adult beetle (For size see description)

Pupa (*Plate XLIV, fig. 12*).—50 mm. long, 22 mm. broad across the thorax; when freshly formed creamy white, later on changing to pale brown. Head slightly deflected, antennæ very long, pass along the thorax on each side and then make a spiral over the respective meta-leg. First two pairs of legs folded over the wing pads and the meta-legs folded below the tips of wing pads. Pronotum shield-shaped and bears one protuberance on each side. Abdominal tip tapering and curved with a sharp upward bend.

Beetle (*Plate XLIV, fig. 13*).—Female $1 \cdot 9 \times 0 \cdot 7$ in., male $1 \cdot 6 \times 0 \cdot 6$ in.; stout; dark brown covered with yellow-ochre pubescence; ventro-lateral sides with a white strip running lengthwise; scutellum white; pronotum with two kidney-shaped orange-yellow spots. Cephalic region of elytra with numerous dark tubercles and one small, sharp tooth on each shoulder. Lateral margins of elytra dark. Light yellow spots of variable numbers on each elytra. Antennæ long, dark brown, 11-segmented, 3rd segment with a row of small teeth on inner edge. Prothorax with a sharp pointed, stout tooth on each side in the middle.

Distinguishing characters of the male and female beetles

Male	Female
1. Antennæ, if folded back, their 3 segments reach beyond the abdominal tip.	1. Antennæ do not approach or exceed the hinder end.
2. The anal end is brown and much wider than that of the female.	2. The anal end is dark black and narrower than that of the male.
3. Elytra reach the anal end.	3. Elytra do not reach the anal end.

VI. Seasonal history

In South India the beetles seem to emerge about the beginning of the rains, in May and October [Fletcher, 1914]. In Baluchistan this insect is apparently most plentiful in July [Stebbing, 1907]. At Lyallpur, in 1932, the beetles started emerging about the end of May and continued to emerge till the end of August. In 1933 the emergence started early in May—the first beetle was seen actually emerging out of a stem on 2 May. The emergence continued till the end of August. The last beetle was observed coming out of a stem on 29 August 1933. The beetles thus emerge during the summer months, and the emergence is at its maximum during the months of July and August, i.e. during the monsoon rains. It may, however, be mentioned that a male beetle emerged from a caged tree in the insectary on 29 October. Usually, however, the beetles do not emerge after August.†

The adult is long-lived and beetles have lived in captivity in the laboratory as long as five months, viz. from June to the beginning of November. The Forest Entomologist has recorded eight months as the maximum life of the beetle in captivity (unpublished records). Thus the egg-laying period may extend from May to the end of October or even the beginning of November. The grub stage is met with in the stem of the attacked trees throughout the year and the pupal stage from November onward.

†The emergence period in North India is from March to August; 50 per cent of the beetles emerge in May and 30 per cent in June (Unpublished records of the Forest Entomologist).

The seasonal history may be summarised as follows :—

May to August . .	Beetles emerge, eggs and grubs are met with, as well as pupæ of the last year are met with.
August to October . .	Oviposition continues, grubs are met with.
November . . .	Grubs of various stages and pupæ are met with.
December to April . .	Grubs in the resting stage and pupæ are met with. In March, however, mostly the pupal stage is present. Rarely, full formed beetles are found in the resting stage within the pupal chambers (observed in the Kulu Valley).

VII. Life-history

Oviposition

The eggs are laid singly. The female beetle cuts, by the repeated action of its strong vertical, sickle-shaped mandibles, a slightly curved transverse slit in the bark of the fig tree. Through the slit thus made the eggs are pushed down under the bark (usually they are completely pushed under the bark). Generally the eggs are deposited in the stem, most frequently near the base, but occasionally they may be laid in the branches. Stebbing [1907] observed the incisions made in the bark by the beetles but was not able to locate the eggs. He stated, ' The eggs have not yet been observed, but they are probably laid either singly or in little clusters on the outside of the bark of the tree or incisions made by the beetle in the outer bark .... ' In Leaflet No. 10 [1918] of the Department of Agriculture Reduit (Mauritius), it is stated ' The eggs are deposited singly in the cracks in the bark, in which the young larvæ remain for the greater part of their life.' According to our observations the eggs are not laid in natural cracks of the bark, but are always laid pushed well under the bark, through the incisions definitely made by the beetle for the purpose.

It has been observed that after an egg has been laid, the female rubs the anal end over the slit from side to side, excreting at the same time a colourless liquid with which the mouth of the slit is covered over.

The method of oviposition would indicate that eggs can only be laid in living plants. However, according to the observations of the Forest Entomologist, oviposition occurs on dead as well as living trees that are not in good health and on roots of trees exposed by erosion, etc. (unpublished records of the Forest Entomologist). This requires confirmation. So far as our observations go the eggs are never laid on dead trees.

The eggs may be laid at any time during day or night.

Number of eggs laid by a female

Five pairs of freshly emerged beetles were liberated on caged fig trees on 22 August 1933, and transferred from one tree to another, and the record of eggs laid by them is given in Tables I and II. From 23 August 1933 to 26 September 1933 these five pairs were kept together and, therefore, their egg-laying record is collective. From 26 September 1933 onward each pair was kept separate and transferred from one cage to another every day and supplied with a fresh fig branch. The largest number of eggs laid by one female in 24 hours was seven. These five beetles laid 513 eggs in all. The Forest Entomlogist, Dehra Dun records up to 200 eggs laid by a female (Unpublished records).

Table I

Record of egg-laying of five females of Batocera rufomaculata *De Geer during 1933*

Date of oviposition	Number of eggs laid by 5 females	Total	Date of oviposition	Number of eggs laid by 5 females	Total
1st tree—					
24 Aug. . . .	4	4	11 Sept. . . .	6	
2nd tree—			13 " . . .	5	
26 Aug. . . .	7		15 " . . .	4	
27 " . . .	6		17 " . . .	6	25
28 " . . .	8	21	5th tree—		
3rd tree—			19 Sept. . . .	10	
3 Sept. . . .	4		20 " . . .	25	
5 " . . .	6		21 " . . .	35	
7 " . . .	8	18	22 " . . .	15	
4th tree—			23 " . . .	20	
10 Sept. . . .	4		24 " . . .	25	130
				Total	198

Table II

Record of egg-laying of the same five females after separating them in different cages from 26 September 1933 onward

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
27 Sept.	3	1	3	..	..
28 "	5	2	4	7	7
29 "	..	2	2	..	..

TABLE II—*contd.*

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
30 Sept.	1	4	2	4	3
1 Oct.	1	4	5	6	5
2 ,,	..	1	4	2	4
3 ,,	3	..	3	4	3
4 ,,	2	..	1	4	2
5 ,,	..	2	..	1	1
6 ,,	..	..	..	..	1
7 ,,	7	3	5	9	4
8 ,,	4	..	5	5	4
9 ,,	4	4	5	5	3
10 ,,	1	1	4	1	1
11 ,,	1	..	1	2	..
12 ,,	1	..	..	..	..
13 ,,	3	1	5	4	2
14 ,,	2	2	5	3	5
15 ,,	2	1	1	4	1
16 ,,	..	..	1	2	2
17 ,,	..	..	1	..	..
18 ,,	..	..	..	..	..
19 ,,	1	1	1	1	2
20 ,,	2	1	5	2	4
21 ,,	2	..	2	2	..
22 ,,	1	1	3	2	..
23 ,,	..	..	6	1	2
24 ,,	..	..	3	..	..

TABLE II—*concld.*

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
25 Oct.	1	1	5	1	5
26 ,,	..	1	2	1	2
27 ,,	..	..	2	..	..
28 ,,	Died	..	..	..	..
29 ,,		..	2	..	1
30 ,,		..	3	..	..
31 ,,		..	3	..	..
1 Nov.		..	3	..	..
2 ,,		Died	Died	Died	1
3 ,,					Died
Total	47	33	97	73	65

Hatching

The grub hatches out from the end of the egg which is towards the opening of the slit, i.e. the micropylar end, but it tunnels into the bark without exposing itself. In case the egg projects beyond the slit, the grub on hatching is unable to bore into the bark and perishes.

Conditions necessary for hatching

It has been observed that moisture is essential for hatching, and embedded in the tissue of the plant, the egg gets the moisture required by it. Some of the eggs were taken out and kept in glass tubes without moisture, and some in a tube with a moist piece of cloth. The eggs in the dry tubes shrivelled up, while those under moist conditions hatched out.

Incubation period

The duration of the egg stage varies from 7 to 14 days, most of the eggs hatching within seven to ten days (Table III).

Feeding habits of the grub

The grub feeds on the inner portion of the bark and xylem. Its path is zigzag. Evidently the grub cuts more fibres than it can actually eat, and these fibres are thrown out. It has been stated by Stebbing [1914] that 'the

tunnel is blocked behind by the excreta of the larvæ, the portion occupied by the latter being full of sap'. It has been definitely ascertained that the tunnel is filled up not by mere excreta, but by excreta mixed up with a large amount of fibrous matter, which has not passed through the alimentary canal of the grub. By shaking material from the tunnel of a grub in a small amount of water, the fibre and small rounded grains of excreta can be easily distinguished. The excreta just coming out from the anal end of the grub was also examined and compared with the fibrous matter in the tunnel and was found to be different.

The grubs feed upon the inner portion of the bark for a considerable period, making a zigzag tunnel, and filling it behind with frass. They enter into the wood when they are sufficiently grown up. It has also been observed that if an egg is deposited on a small branch, then the grub enters into the wood very soon and its path is not zigzag. It enters into the wood of the branch and makes a straight tunnel into the heart of the wood.

Duration of the grub stage

The duration of the grub stage varies from about three to over six months (Table III). Fletcher [1914] states ' the larval stage probably lasts over a long time—possibly several years '. Evidently this is not correct, or at any rate is not usual.

Resting

The grubs become full-grown by about the end of September to the middle of November and prepare elliptical chambers for resting and pupation, stop feeding and remain in the resting stage throughout the winter. In rare cases, however, they may pupate in November and the beetles are formed. These beetles continue in the resting stage throughout the winter and right up to the end of April.

Pupation

The pupation takes place in an elliptical chamber within the stem, usually at a distance of about two inches from the surface, therefore the adult beetle has to cut its way out. The pupa lies naked inside the chamber.

Duration of the resting and pupal stage

The duration of the resting and pupal stages varies from about four to seven months (Table III). This includes the resting larval stage and the immature beetle stage. Stebbing [1914] considered the pupal stage as 3 to 3½ months in duration. According to the observations made by the Forest Entomologist, Dehra Dun, the pupal period lasts for three to four weeks and is followed by an immature beetle stage of variable duration (unpublished records).

Emergence of the beetle

The beetle emerges by cutting out its own passage starting from the pupal chamber and terminating in a circular exit hole of about 0·7 to 0·8 in. diameter. The tunnel is always of variable length.

TABLE III

Duration of various stages of Batocera rufomaculata *De Geer*

Date of caging the beetles	Date of egg-laying	Date of hatching	Duration of egg stage (days)	Date of* entering the resting stage	Duration of the active larval stage (days)	Date of emergence	Duration† of resting and pupal stages (months)	Total life-cycle (months)
2 June 1932	5 June 1932	17 June 1932	12	26 Sept. 1932 to 15 Nov. 1932	99 to 148	29 Oct. 1932 2 May 1933 8 ,, 1933 12 ,, 1933 30 ,, 1933	6 to 7	11 to 12
10 Sept. 1932	16 Sept. 1932	30 Sept. 1932	14	2 Apr. 1933	182	4 Aug. 1933	4·07	10·6
22 Aug. 1933	24 Aug. 1933	31 Aug. 1933	7	March 1934	About 180 days	July and August 1934	4 to 5	10 to 12
Do.	26 Aug. 1933	2 Sept. 1933	8	Do.	Do.	Do.	4 to 5	10 to 12
Do.	3 Sept. 1933	12 Sept. 1933	9	Do.	Do.	Do.	4 to 5	10 to 12
Do.	15 Sept. 1933	25 Sept. 1933	10	Do.	Do.	Do.	4 to 5	10 to 12
Do.	19 Sept. 1933	26 Sept. 1933	7	Do.	Do.	Do.	4 to 5	10 to 12

* Date of entering the resting stage means the date when the pupal chamber has been completed and the grub starts rest before pupation.

† The duration of the resting and pupal stage includes resting larval, pupal and immature beetle stages.

Number of broods

It is evident from the above that there is only a single brood in a year.

VIII. Damage

Damage done by the beetle

The beetle feeds upon the bark of young twigs, petioles of leaves and even the fruit of fig trees. The buds of the attacked twigs wither, the shoots remain stunted, and the leaves of which the petioles are damaged fall off. However, the damage done by the beetle is not of any great consequence. It is the grub stage which is the most harmful.

Damage done by the grubs to the tree

The grubs do not kill the tree outright and this led Stebbing [1914] to remark, ' Up to the present it has not been definitely proved that this pest kills the trees '. Even a severely attacked tree may continue to live for a considerable time, even years, but finally it dries up. The tree only succumbs to the attack when the inner portion of the bark has been totally destroyed from all round the stem. If a branch is attacked, that branch alone would dry up. In cases of severe attack, the bark cracks, and the inner wood is damaged by numerous galleries. It should, however, be noted that if a grub mainly tunnels the wood and the bark remains intact, the tree is not killed.

In our Field Laboratory six beetles were liberated on a fig tree on 2 June 1932. They laid several eggs, the grubs continued to feed upon the stem and ultimately the tree completely dried up. Besides, as stated previously there were 53 fig trees in the Experimental Fruit Garden at Lyallpur. Out of these only three survived an onslaught of this pest. Further, it is a matter of common observation that fig trees do not live very long because of this pest. The report of the Department of Agriculture, British Virgin Islands [1920] also shows that the pest has destroyed nearly all the native fig trees in that island.

IX. Symptoms of attack

Early symptoms

Only a trained eye can discover the early symptoms of attack.

As stated above, the female beetle makes very characteristic transverse slits on the main stem, more frequently near the base and sometimes on the thick limbs of the fig plant. They are moist on account of the sap oozing out of the fresh cuts. On opening up these slits one can discover the eggs.

After a few days a dark brown streak, consisting of the fibrous matter mixed up with the excreta of the freshly hatched grub, is seen coming out of the hole of entrance of grub. As the attack progresses, the quantities of excreta and fibrous matter passed out increase and sap also oozes out of the hole.

When the beetles are about, a very careful examination of the bark, the petiole of the leaves, and the fruit may reveal marks of feeding. A more careful search among the branches may reveal the beetle itself. The beetle when caught makes a shrill piercing noise, which it produces by rubbing the scraper on the hind edge of its pronotum over the file on the mesonotum.

Later symptoms

When the attack has progressed further one can see, even from a distance, a mass of woody frass below an attacked portion of the stem or a branch. The bark over the attacked portion cracks and most of woody fibre filling the burrow thus becomes visible. In case of an old or severe attack one can see numerous circular holes on the trunk or the branch, indicating that the beetles have emerged out of these.

X. Preventive and protective measures

Three different methods were tried in May 1932, just before the egg-laying period to protect the plants.

(*a*) Wire gauze (1/16 in. mesh) was wrapped round the stem of 22 fig trees. No attack appeared on the protected parts but the beetles attacked the unprotected portions.

(*b*) Lime was applied to the stem of eight trees, but this proved of no avail.

(*c*) Coal tar was similarly applied to eight trees, but this could protect the treated portion only. Coal tar painted papers were wrapped on the stem of a plant under a cage and beetles liberated in this. It was found that no eggs were laid.

Trial of spraying the stem and main branches with repellent mixtures.

In an orchard at Nurpur near Pathankot, there has been a constant trouble of the fig borer for the last several years on mango and fig trees. Several trees have been killed from year to year, and the trouble was noticed to be very serious early in 1939. The attacked trees were treated by plugging the tunnels with cotton-wool soaked in kerosene oil and plastering with mud ; all the grubs were killed by this method. For the prevention of any further attack five sprayings were given with repellent mixtures so as to provide a poisonous coating on the bark. The treatment resulted in a complete protection to the trees. The total number of trees thus treated was 110 mango and 10 fig trees. Sprayings were started just before the oviposition period and continued throughout the summer at varying intervals.

As a result of the sprayings, no oviposition was noticed on any tree except in the case of one fig tree on an unsprayed area of a branch, which rather proved the efficacy of the treatment.

It is evident, therefore, that by using wire gauze (1/16 in. mesh) or coal-tar-painted paper and spraying on the stem and thick branches with repellent mixtures the stem of a fig tree can be protected against oviposition.

Where the attack by the pest is bad, all trees which are heavily infested and are drying up should be cut and burnt. Dead branches of trees should also be cut and similarly destroyed.

Any beetles seen in garden should be captured and killed. Beetles can be collected during daytime feeding upon the top-shoots.

Trees should be examined frequently from May to October, and any fresh attack on a branch or a stem attended to.

If some fibrous substance is coming out of a slit, then a larva is very likely to be present. In early stages it lies very close to the opening of the slit and can be taken out by opening the slit with a sharp knife.

XI. Control

Injecting kerosene oil.—Most successful results were obtained by injecting kerosene oil by means of a syringe into the holes in the stem of trees having linear tunnels made by the grubs.

In an experiment eight trees were thus treated with kerosene oil. The tunnels made by the grubs were cleaned out by means of a wire and the oil was syringed so as to reach the wood. One and a half bottles of kerosene oil costing three annas and nine pies were used for eight trees, the cost per tree coming to six pies. The holes were closed with mud after this treatment. In cases where the tunnel is zigzag it was cleaned as far as possible and plugged with cotton-wool soaked in kerosene oil and finally plastered with mud. Fletcher [1914] recommends a mixture of two parts of chloroform and one part of creosote to be injected into the holes. The liquid may either be injected by means of a syringe or an ordinary bicycle oiling can. Another method is to soak cotton-wool in kerosene oil or chloroform and creosote mixture and plug the hole with it.

Potassium cyanide.—At Jahankhelan in the Hoshiarpur district, in an orchard of 33 fig trees, 11 were found attacked by *Batocera* grubs. Three trees were treated by introducing into each hole in the region of wood a small crystal of potassium cyanide weighing about 2 grains. The holes were closed with mud. The grubs were killed and no injury was done to the trees. This method, however, requires very careful manipulation.

XII. Summary

The various stages of *Batocera rufomaculata* de Geer are described.

The female cuts by means of its mandibles a transverse slit in the bark and pushes the egg through this slit. The grub hatches out in 7 to 14 days and tunnels into the bark, following a zigzag path. The tunnel is filled up with chewed fibre and fæcal matter. The active grub stage lasts for about six months and when full grown, the grub prepares an elliptical pupal chamber and enters on resting stage prior to pupation, when it stops feeding. Pupation takes place inside the chamber and the beetle emerges in about four months by cutting out its own passage. There is only one brood in the year. The beetles appear every year from May to the end of August and continue living up to November.

The attack by the beetles can be prevented by protecting the stem with coal-tar-painted paper or wire gauze (1/16 in. mesh) or spraying on the stem and thicker part of branches with a strong repellent mixture. By killing young larvæ, or by injecting kerosene oil or chloroform-creosote mixture into the holes from which frass is coming out or by cleaning the tunnel and plugging it with cotton-wool soaked in kerosene oil and finally plastering the hole with mud, the pest can also be controlled.

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THE INFLUENCE OF THE RAINFALL DISTRIBUTION ON THE COTTON YIELDS AT THE GOVERNMENT EXPERIMENTAL FARMS AT AKOLA AND JALGAON*

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THE Bombay province and the Central Provinces and Berar are important cotton-growing tracts covering about 60 per cent of the total area under cotton in India. In these two provinces the crop is grown extensively in the East and West Khandesh districts of the Bombay province and the districts of Berar. Over this tract the climate and soil characteristics are more or less the same and so the season, the crop and the methods of cultivation are more or less similar. Cotton is generally sown by the second week of June, usually after the first fall of 2 in. of rain. Its period of quickest growth is during August-September. The crop becomes ready for first picking during October. About four pickings are obtained during the growth period of the crop. The Khandesh crop is early by about a fortnight.

Akola is a representative centre of the Berar tract and has a Government experimental farm for the study of the cotton crop. The farm was opened in June 1906 and regular work began in 1907. The soil of the farm is a deep black loam typical of the Berar tract. A series of cotton yield-data extending over a period of 28 years commencing from the season 1907-08 was kindly supplied by the Director of Agriculure, Central Provinces and Berar.

Jalgaon is situated in the East Khandesh district of the Bombay province and has a Government experimental farm for the study of the cotton crop, which was started in 1913-14. The soil of the farm is deep black. A series of 23 years' data on cotton-yield from 1913-14 was kindly made available by the Director of Agriculture, Bombay province.

The above two series of yield-data form the basis of this paper in investigating the influence of the quantity and distribution of rainfall on the cotton yield. The yield-data of cotton supplied relate to the average yield per acre over the farm as a whole and not to any one particular plot. The results of investigation on the Akola series alone have been already discussed by Kalamkar and Satakopan [1935].

* This investigation was undertaken in the Agricultural Meteorology Section, Meteorological Office, Poona, when the section was financed by the Imperial Council of Agricultural Research.

The yields of seed cotton in lb. per acre at the two farms are given in Table I. The average yield of seed cotton at the Akola Farm was 443 lb. per acre, with a standard deviation of 213 lb., and at Jalgaon it was 485 lb. per acre with a standard deviation of 165 lb. The yields were highly variable, their coefficients of variability being 48 and 34 respectively for the two farms.

The two series of yields were subjected to an examination for secular changes by fitting polynomials of the 5th degree [Fisher, 1925]. The values of x's for the two series are shown below :—.

	Akola	Jalgaon
Mean	442·9	484·7
x'_2 . . .	+280·7	—68·2
x'_3 . . .	+131·2	—173·0
x'_4 . . .	+19·0	+143·6
x'_5 . . .	—346·5	—52·5
x'_6 . . .	+164·8	+87·9
Standard residue .	211·0	176·9

For both the series none of the values of the x's is significant when compared with the standard residue, indicating that there are no secular changes in the series of yields.

For studying the effect of rainfall on the yield of cotton the period 22nd May to 23rd October is considered. This period is divided into 31 sub-periods, each of five days. The total rainfall in each five-day period is computed from the daily rainfall records of the two stations for all the years required. A fixed calendar date rather than the date of sowing has been used as a reference point for the season for convenience. The choice of a five-day period for a unit of time, although arbitrary, is believed to be fine enough to represent the rainfall distribution and also its effect in general on the growth of the crop, and the agricultural operations, such as interculture, weeding, etc.

The 31 five-day rainfall figures for each year have been fitted with a polynomial of the 5th degree and a set of six constants a', b', c', d', e' and f' is obtained to represent the distribution. These constants which are given in Tables II (a) and II (b) for the two stations are later used as independent variates with which the crop yield is correlated to obtain a regressional integral according to the method developed by Fisher [1924]. Each series of the distribution constants in Tables II (a) and (b) has been examined for the presence of secular changes over their respective periods. Tables III-a and III-b give the values of x's together with their standard residues.

TABLE I

Yield of seed cotton in lb. per acre at Akola and Jalgaon

Year	Yield at Akola	Yield at Jalgaon
1907-08	258	..
1908-09	342	..
1909-10	504	..
1910-11	259	..
1911-12	570	..
1912-13	486	..
1913-14	509	277
1914-15	564	387
1915-16	682	777
1916-17	60	623
1917-18	179	112
1918-19	218	596
1919-20	771	545
1920-21	55	598
1921-22	513	626
1922-23	216	484
1923-24	456	603
1924-25	334	537
1925-26	393	352
1926-27	378	573
1927-28	782	441
1928-29	662	360
1929-30	753	614
1930-31	657	642
1931-32	150	153
1932-33	583	529
1933-34	433	527
1934-35	634	290
1935-36	..	502
Mean	443	485
S. D.	213	165
C. of V.	48	34

It is interesting to compare the mean values of the rainfall distribution constants for the two stations given in the first rows of Tables III-*a* and III-*b*. The mean values for the two stations show good agreement and the differences will be seen to be not significant in the light of the pooled estimates of errors. This indicates that the average amount as well as distribution of rainfall for the two stations are more or less similar.

TABLE II-*a*

Rainfall distribution constants—Akola (unit $\frac{1}{1000}$ in.)

Year	a'	b'	c'	d'	e'	f'
1907	620	—122	—157	+73	+19	—4
1908	1,108	—170	—249	+103	—40	—4
1909	784	—96	—142	+39	—30	—5
1910	1,105	—38	—178	+5	—58	+8
1911	623	—129	—109	+57	—13	—6
1912	608	—95	—154	+84	+6	—29
1913	869	—133	—210	+67	0	+1
1914	859	—15	—143	—27	—72	+23
1915	867	—18	—177	+65	—12	—46
1916	1,334	—40	—169	+51	+22	+30
1917	936	+46	—38	—45	—48	—4
1918	398	—175	+15	+9	+3	—7
1919	824	—168	—62	+60	—68	—1
1920	338	—37	—63	+27	—25	—3
1921	773	—52	—147	+9	—24	+5
1922	954	—135	—240	+113	+3	—72
1923	707	+60	—139	—11	—45	—5
1924	1,107	+219	—176	—100	+8	+50
1925	622	—88	—119	+34	+38	—1
1926	987	—101	—306	+89	+57	—37
1927	912	+22	—19	+47	—164	—70
1928	880	+56	—30	0	—76	+50
1929	681	—209	—67	+131	—112	—7
1930	892	+84	—134	—124	—73	+41
1931	1,130	+256	—106	—6	—49	—80
1932	830	—7	—207	+30	+21	0
1933	1,215	—71	—156	+4	—35	+35
1934	1,056	—67	—318	+45	+83	—3

TABLE II-*b*

Rainfall distribution constants—Jalgaon (unit $\frac{1}{1000}$ in.)

Year	a′	b′	c′	d′	e′	f′
1913-14	904	—146	—230	+78	+12	—9
1914-15	1,197	—69	—265	+36	—30	—28
1915-16	966	+78	—90	+83	—67	—92
1916-17	995	—41	—150	+92	+38	—5
1917-18	778	+125	—19	—70	—70	—26
1918-19	421	—123	—55	+37	—4	—7
1919-20	966	—95	—61	+1	—44	—2
1920-21	399	—56	—101	+58	—2	—35
1921-22	928	—156	—183	+82	—28	—2
1922-23	686	—15	—113	+13	—73	—16
1923-24	1,014	—32	—285	+66	+21	—77
1924-25	787	+66	—30	+38	—30	—15
1925-26	526	—83	—126	+30	+29	—10
1926-27	705	—15	—221	—13	56	+25
1927-28	855	—69	—142	+98	—59	—73
1928-29	787	+86	—103	+24	—41	—39
1929-30	697	—217	—78	+141	—95	—17
1930-31	1,380	+46	—225	—119	—138	+70
1931-32	1,659	+364	—61	+50	—106	—137
1932 33	937	—35	—248	+45	+23	—11
1933-34	1,201	—74	—137	—119	—43	+84
1934-35	1,484	—135	—407	+42	+71	+36
1935-36	823	—50	—213	+47	—13	—26

TABLE III

Secular changes in rainfall constants

—	a'	b'	c'	d'	e'	f'
(a) Akola						
Mean . .	+857·82	—43·68	—142·86	+29·61	—24·43	—5·03
x'_2 . . .	+254·01	+219·11	—0·14	—77·03	—11·67	+0·76
x'_3 . . .	+311·49	—52·94	—159·39	+39·70	+34·11	+13·01
x'_4 . . .	+170·05	—45·14	—52·00	—16·98	+67·71	+13·91
x'_5 . . .	—92·17	—101·54	—78·36	+20·98	+113·05	+5·72
x'_6 . .	+73·20	—53·04	—153·93	+30·38	+53·65	—2·16
S. R. . .	239·9	09·3	73·6	61·2	47·9	36·5
(b) Jalgaon						
Mean . .	+917·17	—28·09	—154·04	+32·17	—25·78	—17·91
x'_2 . . .	+474·32	+60·70	—118·85	—64·35	—14·55	+47·75
x'_3 . . .	+616·43	—45·82	—181·62	—6·04	+33·82	+26·13
x'_4 . . .	—342·78	—77·10	+38·52	—20·12	+58·96	+19·77
x'_5 . . .	—393·98	—178·99	—143·84	+74·20	+89·76	—2·85
x'_6 . . .	—237·12	+87·13	+69·06	+48·70	—20·61	—52·87
S. R. . .	267·0	125·0	86·4	67·2	53·5	51·4

For Akola, the mean five-day rainfall does not show any trend over the period of 28 years ; some of the other rainfall distribution constants, however, show tendencies of slow changes. For example, b' shows an upward trend as indicated by its value of x'_2. Significant changes have also occurred in the rainfall distribution constants c' and e' as is seen from the values of x'_3 and x'_6 for c' and of x'_5 for e'. This shows that while the total rainfall at Akola has not changed over the period under consideration, its distribution over the season shows slight changes. The secular changes in the distribution of rainfall at Akola over a period of 65 years has been studied in another paper [Satakopan, 1936].

At Jalgaon the amount of rainfall shows a slight secular change as indicated by the value of x'_3 for the a' constant. The constant e' also shows a similar change.

The series of yields for the two stations were correlated with their respective distribution constants for rainfall to find out the effect of the rainfall and its distribution on the yield. The correlation coefficients after eliminating the secular changes from both the yield and rainfall constant series were determined. These coefficients together with the direct coefficients without eliminating the secular changes are given in Table IV.

TABLE IV

Correlation coefficient of yield with	Akola		Jalgaon	
	Direct correlation coefficient	Correlation coefficient after eliminating secular trend	Direct correlation coefficient	Correlation coefficient after eliminating secular trend
a'	—0·078	—0·237	—0·292	—0·140
b'	—0·147	—0·341	—0·366	—0·450
c'	0·058	0·138	0·003	0·221
d'	0·082	0·164	0·154	0·162
e'	—0·375	—0·375	0·005	0·024
f'	0·072	0·067	0·190	0·275

It will be seen that the correlation coefficients, though small, have increased in many cases after eliminating the secular trend in the yield and the rainfall distribution constants.

The sums of squares and products of the rainfall distribution constants among themselves, after correcting for the secular changes, are given in Table V. Fisher's method was used to solve the six simultaneous equations to obtain the six coefficients of regression of the rainfall distribution constants on the yield separately for the two stations. In Table VI are given the matrices of multipliers each of which is the co-factor of the corresponding number in Table V divided by the value of the corresponding determinant.

The regression coefficients of the various rainfall constants on the yield are obtained by multiplying the sums of products of yields and the rainfall constants after correcting for the secular changes, by the various figures in the corresponding column of the matrix of multipliers and adding up. The

fegression equations expressing the yields in terms of the distribution constants for the two stations are :

Akola

$$Y^* = -0{\cdot}432\,a' + 0{\cdot}328\,b' \quad -1{\cdot}285\,c' + 1{\cdot}317\,d' \quad -3{\cdot}033\,e' + 2{\cdot}067\,f'$$

Jalgaon

$$Y^* = -0{\cdot}149\,a' + 0{\cdot}191\,b' \quad -0{\cdot}802\,c' + 1{\cdot}573\,d' \quad -1{\cdot}399\,e' + 2{\cdot}178\,f'$$

Though the coefficients have different values it is interesting to note that they have similar signs for the two stations indicating similar relationship in general.

The data for the two stations, as has already been observed, are available only for short periods. They may also be combined to arrive at an estimate of the average relationship of the yield with rainfall in the area which they represent. It is expected that the results, being based on a larger number of observations than is available at one station, will be more reliable, though it must be recognised that the relationship thus deduced will probably be not exactly representative of the situation at either of the two stations. The pooling of the sums of squares and products in Table V together to form a combined regression equation has also a limitation that if there is any extraneous source of variation in yield common to the two stations in one year when the rainfall constants are similar it will introduce an error in the regression formula [Hopkins, 1935].

TABLE V

Sums of squares and products of rainfall distribution constants after correcting for trend

(*a*) *Akola*

a' . . .	+1265938					
b' . . .	+207647	+262798				
c' . . .	—172697	—740	+119196			
d' . . .	—42582	—106029	—26566	+82333		
e' . . .	—11060	—2988	—44938	+7808	+50417	
f' . . .	+14833	+8139	+7332	+26946	+251	+29376

(*b*) *Jalgaon*

a' . . .	+1212281					
b' . . .	+238825	+265595				
c' . . .	—134452	+58305	+126797			
d' . . .	—31634	—34158	—4997	+76742		
e' . . .	—45086	—33013	—41072	+12887	+48717	
f' . . .	—45718	—59804	—16785	—33124	+8481	+44868

*Y, a', b', etc. in the equations represent departures of the respective variables from their polynomial values.

TABLE VI

Matrices of multipliers

a'	b'	c'	d'	e'	f'
		(a) Akola			
+2·72759	—6·21017	+7·90718	—7·70520	+8·43043	—8·77007
—6·21017	+25·78191	—20·59118	+37·22662	—23·90910	+35·48341
+7·90718	—20·59118	+36·78337	—23·70542	+36·72445	—29·52666
—7·70520	+37·22662	—23·70542	+73·47607	—32·07296	+67·16532
+8·43043	—23·90910	+36·72445	—32·07296	+57·26049	—36·70802
—8·77007	+35·48341	—29·52666	+67·16532	—36·70802	+97·93120
		(b) Jalgaon			
+1·96645	—3·44389	+4·59228	—2·93743	+4·82221	—3·94872
—3·44389	+21·47110	—10·68097	+29·13231	—13·20264	+45·11634
+4·59228	—10·68097	+22·29350	—10·46298	+20·81640	—12·87640
—2·93743	+29·13231	—10·46298	+64·14781	—23·33652	+83·69135
+4·82221	—13·20264	+20·81640	—23·33652	+45·10136	—30·65014
—3·94872	+45·11634	—12·87640	+83·69135	—30·65014	+141·16104

The combined regression equation obtained was :

$$Y = -0{\cdot}240\,a' \quad -0{\cdot}100\,b' \quad -0{\cdot}856\,c' \quad +0{\cdot}939\,d' \quad -2{\cdot}040\,e' \quad +1{\cdot}447\,f'$$

The values of yields were then calculated for the various years using this regression equation for both stations. These are plotted with their actual values in Fig. 1. Comparatively large differences are observed between the actual and calculated values of yields for the years 1910-11, 1915-16, 1919-20, 1920-21 and 1931-32 at Akola and for 1915-16 and 1917-18 at Jalgaon. The peculiar features of these years are indicated below.*

* The causes of the large deviations of the calculated from the actual values can be grouped under two heads : (*a*) Effects of factors that have not been taken into consideration in evolving the regression equation, *e.g.* November rainfall in 1910-11 at Akola. Heavy rainfall at Akola in November is a comparatively rare phenomenon and hence we have considered only rainfall for the period ending October 23. Unless a long series of records giving many Novembers with varying amounts of rainfall is available it is not possible to express the effect mathematically and include the same in the regression equation. (*b*) Effects due to the inadequate representation of the dependent variate. The mathematical representation of the rainfall distribution by a smooth curve has this natural limitation. We are fitting here a smooth curve to an essentially discontinous variable in point of time. No mathematical function which is continuous can take into

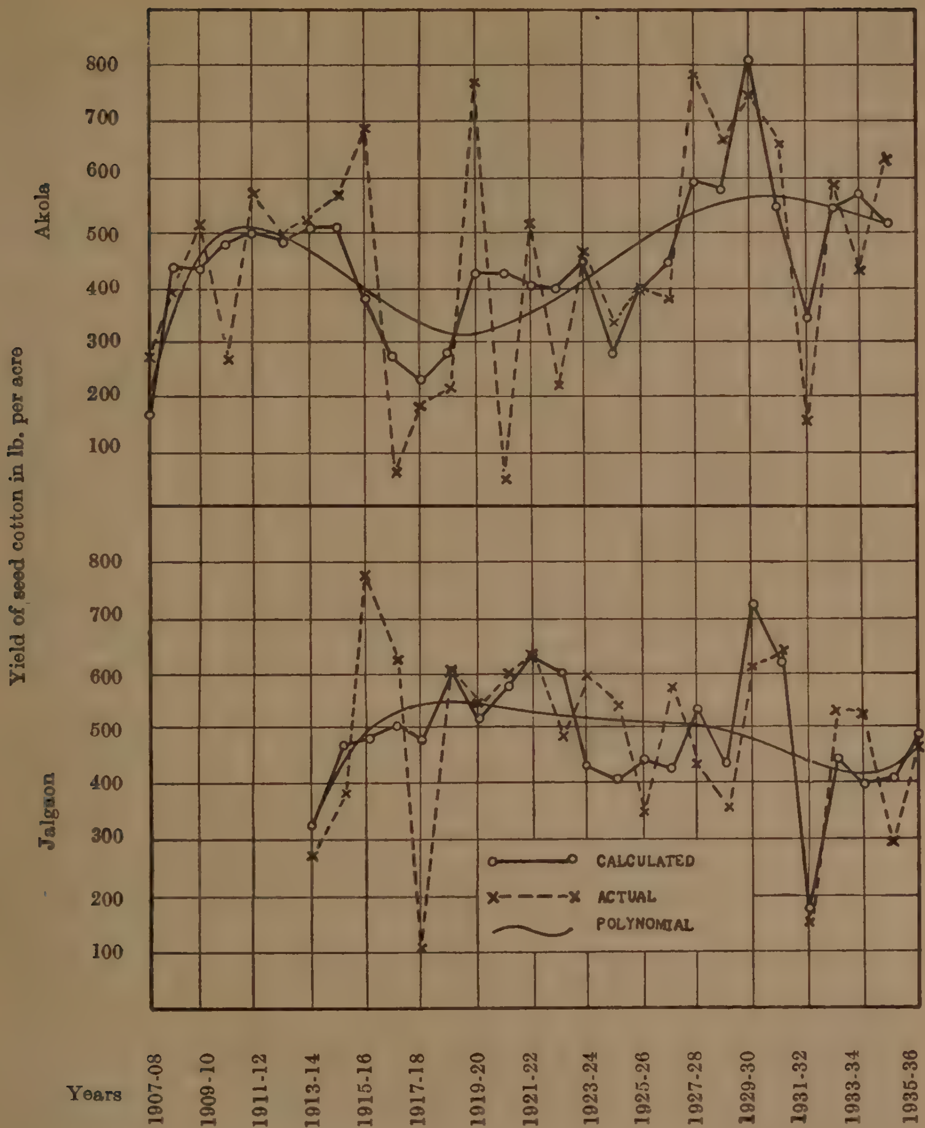

Fig. 1. Calculated and actual yields of seed cotton

consideration all the features of a rainfall distribution. As such, effects such as those observed in the year 1915-16 at Jalgaon remain outside the scope of the regression equation determined.

The purpose of recording these explanations for large departures is that the forecaster who uses the regression equation may, after determining the yield for any year from the equation, modify the value to account for such known effects outside the scope of the equation and give the final forecast.

AKOLA

1910-11.—This year the rains began early and were well distributed throughout the growing season. The first part of the season was very favourable but a fall of rain in the first half of November, a period which is not included in the regression formula, did serious damage to cotton by washing down many of the mature and immature bolls and flowers.

1915-16.—The records at the farm do not show any special notes except that weeding and hoeing operations were taken advantage of fully because of the opportune breaks in the growing season.

1919-20.—This was a remarkable season for the amount of sunshine. There were only 25 rainy days from the 1 July to the end of September and the rainfall was most opportune.

1920-21.—This was an exceptional year. The total rain was only 10·7 in. There was practically no rain for the rest of the cotton season after the first fortnight of July.

1931-32.—The actual yield is even lower than the calculated yield. This may be attributed to the abnormal continuous rain amounting to 9·7 in from 1 to 11 October.

JALGAON

1915-16.—During this year, the rains during the period July 14 to August 6 which would have adversely affected the yield under normal conditions (see response curve) are said to have favoured the crop due to lack of the usual rains up to 14 July. This probably accounts for the high actual yield.

1917-18.—Monsoon broke as late as June 28. Moreover there was hardly sufficient rainfall to keep crops growing till the end of August. Late rains saved the crop from complete ruin.

From the regression coefficients six coefficients expressing the average benefit or loss in lb. per acre ascribable to an additional unit of the distribution constant are determined and these coefficients when combined with the corresponding orthogonal functions of time give a continuous curve showing the average effect in lb. per acre corresponding to an additional inch of rain at any time during the period considered. Such curves which are called 'the response curves' are given separately for the two stations in Fig. 2 and in a combined form in Fig. 3.

It is interesting to note that there is in general a similarity between the two curves for Akola and Jalgaon except towards the end of the season. Both the stations show an adverse effect for an additional inch of rain in the fourth week of May. Heavy and continuous rainfall in the latter half of July and the first half of August affects the yield adversely as it gives rise to weeds and waterlogging and delays weeding and interculture operations. Heavy rain at the end of September or the early part of October damages the cotton crop by causing the shedding of bolls.

The combined curve confirms the observations recorded above. The adverse effect of rain in the fourth week of May is rather difficult to explain. It may be mentioned that the investigation of the effect of monthly rainfall and temperature on cotton yield in the districts of the Bombay province [Kalamkar, Satakopan and Gopal Rao, 1935] has shown that high average maximum

temperature in May is found to have a beneficial effect on yield in the districts of Khandesh, Surat and Ahmedabad, which may be attributable to the fact that under the influence of the hot sun the black cotton soil ' ploughs itself ', and this exerts a beneficial effect on the subsequent crop of cotton on it.

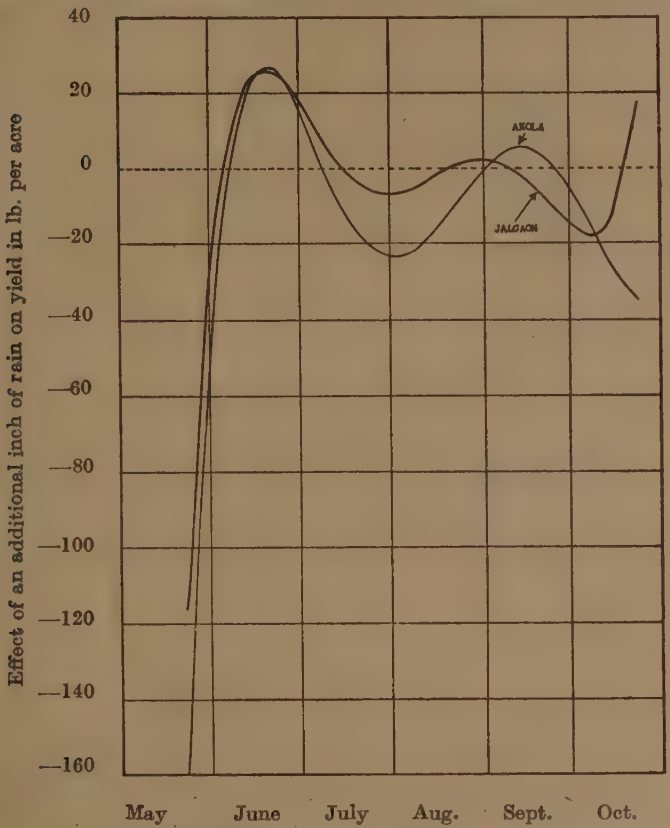

Fig. 2. Response curves for Akola and Jalgaon

Similar adverse effect has been noticed in Gazeira by Crowther [1925] who observes that rainfall in May and June exerts a depressing effect on the yield of cotton sown in the following July or August at Gazeira. He attributes it to the washing off of the nitrates formed in the soil. It may be mentioned in this connection that fortnightly estimations of the total nitrogen in the soil at different depths in the bare plot of the Central Agricultural Meteorological Observatory have been made regularly during the last two-and-a-half years. These data (unpublished) show that the first showers of the season do cause a drop in total nitrogen in the soil. This effect is probably due to leaching. This adverse effect has been also attributed to the possible interference with the soil cracks [Lambart and Crowther, 1935] by rainfall which reduces the rate of drying off of soil and closes the sub-soil cracks, thus preventing adequate sub-soil aeration or water penetration.

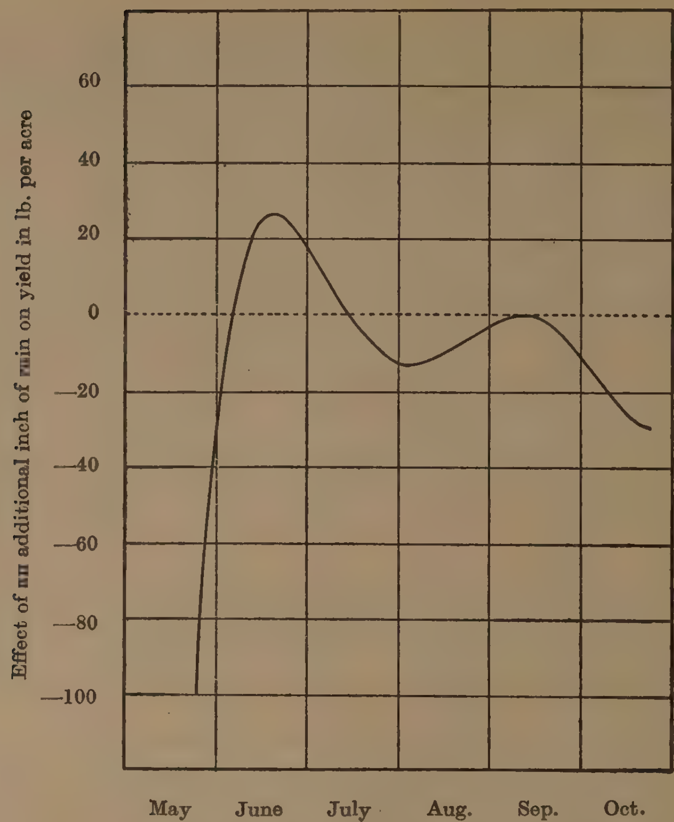

Fig. 3. Response curve (Akola-Jalgaon combined)

Significance of the dependence of yield on the rainfall constants can be tested by partitioning the total sum of squares as indicated in Table VII.

It may be seen that the variances due to regression and the residual do not differ significantly, the multiple correlation coefficients being $R = 0{\cdot}58$ and $R = 0{\cdot}56$ respectively for the two stations. In the analysis of variance for the combined regression, it is seen that the ratio of the mean square due to 'regression' to that due to 'residual' is 2·32 which approaches the 5 per cent point for this ratio, *viz.* 2·39 [Snedecor, 1938]. The multiple correlation coefficient is 0·54. It will be observed that the combination of the two series into one equation shows a slight improvement in the significance of the variance due to 'regression' on account of comparatively larger number of degrees of freedom.

The analysis on the whole indicates that the significance of the rainfall effect is not definitely established from these data at Akola and Jalgaon extending over short periods. It is, however, interesting to note that the response curves showing the average effect in lb. ascribable to an additional inch of rain appears more or less to agree with the usual impressions of the cultivators as regards the influence of rain on the yield of cotton. In this

connection a paper on ' Cotton prospects on the Nagpur Agricultural College Farm ' by McDougal [1935] is of interest.

In conclusion, the authors wish to express their thanks to Dr L. A. Ramdas, Agricultural Meteorologist, Poona, for help in the preparation of this paper.

TABLE VII

Analyses of variance

Factor	D. F.	Sum of squares	Mean square
(*a*) *Akola*			
Regression . . .	6	334,196	55,699
Polynomial . .	5	243,602	48,720
Residual	16	645,451	40,341
Total .	27	1,223,249	45,306
(*b*) *Jalgaon*			
Regression . . .	6	169,082	28,180
Polynomial . . .	5	65,697	13,139
Residual	11	363,246	33,022
Total .	22	598,025	27,183
(*c*) *Akola-Jalgaon* (*Combined*)			
Regression . . .	6	448,057	74,676
Residual	33	1,063,918	32,240
Total .	39	1,511,975	38,769

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THE INHERITANCE OF MEAN FIBRE-LENGTH, FIBRE-WEIGHT PER UNIT LENGTH AND FIBRE-MATURITY OF COTTON

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(With one text-figure)

I. Introduction

There are three well-known methods of improving the quality of a crop—(1) importation and subsequent acclimatization of foreign seed, (2) mass or single line selection and (3) hybridization. Of these, the first method appears to have worked fairly well with virgin soils and a few crops, while the other two methods have offered scope for a wider application. Among these, improvement by selection is generally slow but sure in the long run ; it has also this quality that if improvement is desired in any one character, it may take place simultaneously in a few other characters which are closely linked to the former. Thus, the improvement by this method is generally all-round, with an especial emphasis on a few closely associated characters. The third method—hybridization—is capable, in theory, of yielding spectacular results, but our knowledge of genetics is so imperfect that examples of such successes are not many in practice. It is, however, possible by employing this method to aim at improvement, by crossing and back-crossing again and again, on a few selected characters. For this purpose, it is necessary that the breeder should have some idea of the degree of inheritance of the character or characters which he wishes to introduce or intensify in a progeny with a view to improving it, and that he should also know the degree of variability of these characters due to seasonal or environmental factors so as to assess the true measure of success achieved by him in his work.

For a crop like cotton, which is grown primarily for industrial purposes, the work of the breeder is intimately connected with that of the technologist, the object of the combined efforts of both being to develop new varieties, which on the one hand, should pay more to the farmers and, on the other, should appeal more to the spinner as compared with the old varieties. The higher monetary return to the grower depends partly upon good yield and ginning percentage and partly upon the superior quality of the cotton, while the spinner is mainly interested in the latter, which should enable him to spin finer or stronger yarns from the new variety. Now, a large number of factors

go to make up what is commonly, and somewhat vaguely, known as the spinning quality of a cotton, but chief among them are the mean fibre-length and fibre-weight per inch, the latter being a measure of its fineness. The relative importance of these two fibre properties, it is interesting to note, is somewhat different for the different groups of cotton. For instance it has been found that for the Egyptian cottons the mean fibre-weight per unit length plays the most important part [Turner, 1934] while for the Indian cottons, the mean fibre-length takes the first place among the factors determining their spinning quality [Turner and Venkataraman, 1934]. Another property which, though not so closely connected with the strength of yarns into which a cotton may be spun, has been found to have an important bearing upon their appearance and neppiness is the maturity of its fibres [Gulati and Ahmad, 1935]. These two fibre properties, namely fibre-weight per inch and maturity, are closely interrelated, as both owe their origin to the deposition of protoplasmic material within the cell-walls during the later half of the development of the fibre. It is, however, noteworthy that while the regular and uninterrupted supply of protoplasm to most of the fibres helps to increase the maturity percentage and, therefore, reduce the neppiness in the yarns, it simultaneously tends to increase the mean fibre-weight per inch, which pulls down the spinning quality of a cotton. Therefore, in order that the yarns spun from the new varieties may combine good strength with a reasonable degree of freedom from neps, the cotton breeder, aided by the technologist, must aim at an improvement in staple length and must also strike a happy balance between fibre-weight per unit length and percentage of mature hairs. It is, therefore, essential that a systematic study should be made of the influence of genetical factors upon these three fibre properties and their response, if any, to environmental factors. But in such studies it is not always easy to separate the environmental from the genetical factors, which are partially masked by the former.

The present investigation provides an example of an experiment in which environmental and genetical factors are combined in a single field experiment, so that the effect of the former can be partially eliminated for the effective study of the latter. The experiment was planned and laid out at the Institute of Plant Industry Farm, Indore. The experimental field of which a plan is shown in Fig. 1 comprised ten randomised blocks each measuring 44 ft. × 24 ft. Each block contained 22 plots, out of which two plots on either side (north and south) were left out as non-experimental areas, leaving 18 plots for the experiment. These 18 plots were distributed as follows :

(1) Parent strains, Cwn 520, Bani and Malvi	3
(2) F_1s, viz. Cwn 520 × Bani, Cwn 520 × Malvi, and Malvi × Bani	3
(3) Four progenies of each F_2	12
	18

Unfortunately the material from the four progenies of F_2s was not available ; consequently we have confined our experiments and discussion to three parent strains and their three F_1s which are marked by slanting and cross lines, respectively, in Fig. 1. Each plot consisted of a single row of plants 24 ft. long ; the plant in the row being 1 ft. apart, while the space between two rows was

2 ft. Two plants on either side (east and west) were discarded so as to allow for border effects, leaving 20 plants per plot for experimental work. Since there were 18 plots in a block, the total number of plants was 360 per block, of which 120 belonged to the three parent strains and their F_1s. If all the plants were studied individually we should have to collect material from, and make the tests on, 1,200 plants. However, material from all the plants was not available. Material from 691 plants (classified as in Table I) was received at the Laboratory for testing.

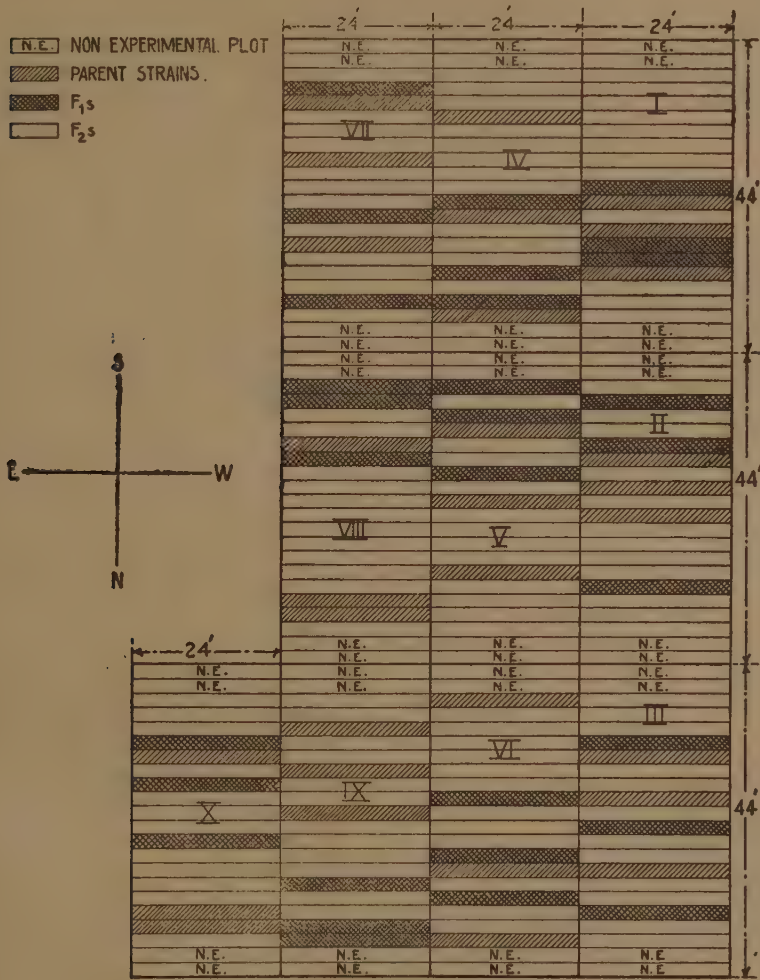

Fig. 1. Sketch plan of experiment 8331/35, I. P. I.

TABLE I

Distribution of samples received for testing

Cotton	Blocks										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Cwn 520	8	6	12	8	10	13	7	6	7	4	81
Bani	14	15	17	13	16	14	12	8	11	16	136
Malvi	12	11	13	11	9	12	5	13	7	7	100
Cwn 520 × Malvi	11	12	13	16	14	13	11	15	16	13	134
Bani × Malvi	14	11	8	6	10	14	12	14	13	17	119
Cwn 520 × Bani	14	15	10	4	7	9	13	17	19	13	121
	73	70	73	58	66	75	60	73	73	70	691

It will be seen from Table I that the minimum number of plants is four for Cwn 520, block X, and F_1 (Cwn 520 × Bani), block IV; consequently, if we keep this number as the minimum for all the plots, the total number of plants available for testing would be $4 \times 60 = 240$. We have, however, tested the material from 120 plants, assuming that two plants per plot would be sufficient for the study of plant-to-plant variation. The selection of the material from two different plants out of the total available for each plot (Table I) was made completely at random. Fibre-maturity and fibre-weight per unit length were determined for each of the 120 samples obtained in this way. The measurement of the mean fibre-length and fibre-weight per unit length of these samples was carried out on the new stapling apparatus [Ahmad and Nanjundayya, 1936], while the technique described in an earlier publication [Gulati and Ahmad, 1935] was followed for the maturity count. The results obtained for these 120 samples provide the material for the study of :—

(1) The genetical variation.
(2) Variation between blocks (major environment).
(3) Variation between plots of the same block (minor environment).
(4) Variation between plants of the same plot (environmental and small genetical contribution due to strain impurity).

II. SEPARATION OF ENVIRONMENTAL AND GENETICAL VARIATION

The data obtained for the individual plants for fibre-weight per unit length, percentage of mature hairs, and fibre-length are given in Tables A B and C in the appendix. The environmental and genetical factors are sorted out by the application of analysis of variance. For this purpose we construct sum and difference tables (similar to the split-plot technique) [Koshal, 1935]. The two values given in Table A for each plot are added and this constitutes the sum table (Table II), while their differences form the difference table (Table III). We illustrate this point by reproducing the two tables for fibre-weight per inch, while similar tables were also constructed, but are not reproduced, for the other two properties, namely mean fibre-length and fibre-maturity.

Table II

Sum table

(Fibre-weight per unit length)

Cotton \ Blocks	I	II	III	IV	V	VI	VII	VIII	IX	X	Total	
Cwn 520	5·81	4·86	4·71	4·80	4·82	5·11	4·93	4·60	5·41	4·68	49·73	
Bani	4·44	4·33	4·34	4·81	4·33	4·38	4·44	4·50	4·45	4·32	44·34	145·37
Malvi	5·14	5·02	4·85	5·55	4·90	5·31	4·88	5·14	5·23	5·28	51·30	
Cwn 520 × Malvi	5·34	4·95	5·11	4·93	4·36	5·58	4·98	5·19	5·10	5·31	50·85	
Bani × Malvi	4·49	4·13	4·89	4·24	4·86	5·23	5·17	4·58	4·76	4·60	46·95	145·59
Cwn 520 × Bani	4·50	4·75	5·07	4·61	4·93	4·93	4·92	4·89	4·69	4·50	47·79	
Total	29·72	28·04	28·97	28·94	28·20	30·54	29·32	28·90	29·64	28·69	290·96	

Table III

Difference table

(Fibre-weight per unit length)

Cotton \ Blocks	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520	−0·23	−0·40	−0·15	−0·58	−0·14	0·23	−0·13	0·24	−0·15	−0·58
Bani	0·34	0·07	0·04	−0·09	−0·11	−0·62	−0·76	−0·24	0·13	0·42
Malvi	0·14	−0·10	0·05	0·01	0·22	0·31	−0·20	−0·20	−0·11	0·42
Cwn 520 × Malvi	−0·16	0·17	−0·65	0·53	0·12	0·04	0·00	0·15	0·28	−0·11
Bani × Malvi	−0·21	0·09	0·11	−0·26	0·42	0·21	0·39	0·16	−0·36	0·12
Cwn 520 × Bani	−0·42	0·05	0·09	−0·01	0·31	−0·05	0·20	0·09	−0·31	−0·28

The 60 values comprising the sum table are analysed in the usual manner, to separate the effects of varieties, blocks, and plot-to-plot variation, and the 59 degrees of freedom are apportioned as shown in Table IV.

Table IV

Preliminary analysis of variance ; fibre-weight per unit length

	D. F.	S. S.	M. S.	F	
Varieties	5	1·754367	0·350873	8·8687	Significant ($P = 0·01$)
Blocks	9	0·415170	0·046130	1·1660	Non-significant
Plot error	45	1·780350	0·039563		
Total	59	3·949887			

It will be seen that the variance due to varieties, which includes practically the whole of genetical variation is highly significant, while the variance

due to blocks (environmental) is non-significant. The variation between plants in the same plot can be calculated in two ways :—

(1) The total sum of squares corresponding to 119 degrees of freedom is obtained from the individual plant data of Table A (Appendix) and from this the total sum of squares for 59 degrees of freedom given in Table IV is deducted. The balance will be sum of squares for variations between plants in the same plot, corresponding to 60 degrees of freedom.

(2) The figures given in difference table (Table III) are squared and the resulting sum is divided by 2. This will also provide a check on the calculations.

The complete analysis of variance is given in Table V.

TABLE V

Analysis of variance ; fibre-weight per unit length

	D. F.	S. S.	M. S.	F.	
Varieties	5	1·754367	0·350873	8·6603	Significant for $P = 0·01$
Blocks	9	0·415170	0·046130	1·1386	Non-significant
Plot error	45	1·780350	0·039563 } 0·040515		
Plant error	60	2·473700	0·041228 }		
Total	119	6·423587			

The significance of plot error is judged from the plant error, and since it is non-significant, both can be combined to give 105 degrees of freedom for error. From this analysis it is evident that the evironmental factors (major and minor) are non-significant, and the major portion of the variation, being due to varieties, is of genetical nature.

The results of application of analysis of variance to the data obtained for maturity percentages and mean fibre-length are shown in Tables VI and VII.

TABLE VI

Analysis of variance ; percentage of mature hairs

	D. F.	S. S.	M. S.	F.	
Varieties	5	839·57	167·914	3·624	Significant ($P = 0·01$)
Blocks	9	368·87	40·985	1·026	Non-significant
Plot error	45	2469·43	54·876 } 46·337		
Plant error	60	2396·00	39·933 }		
Total	119	6073·87			

TABLE VII

Analysis of variance ; fibre-length

	D. F.	S. S.	M. S.	F.	
Varieties . .	5	1·89975	0·37995	58·962	Significant ($P = 0\cdot01$)
Blocks . .	9	0·11634	0·012927	2·006	Non-significant
Plot error . .	45	0·28998	0·006444	1·804	Significant
Plant error . .	60	0·21425	0·003571		
Total .	119	2·52032			

The relatively small influence of environment on both the fibre-weight per unit length and the mean fibre-length has also been recently pointed out by Barre [1938]. In this experiment 16 varieties of cotton from the same seed stock were grown at 14 different places across the cotton belt in order to study the influence of variety, soil, climate and season on their fibre properties and spinning value. The results of one season indicate that both fibre-weight per unit length and fibre-length are inherited in a definite way, and that the influence of environment is small.

III. Genetical variation in fibre-weight per unit length, fibre-maturity and fibre-length

The total variability with respect to any measureable character may be divided into two classes, (1) Genetic variance, (2) Environmental variance. In a randomised block experiment, such as the one we are discussing, the main environmental effects are equalised between blocks, and the minor effects are distributed at random within blocks. For statistical purposes the various genetical factors may be divided into two parts :—

(*a*) An additive part which reflects the genetic nature without distortion, and

(*b*) the non-additive part which represents the deviation from the direct effects of the different Mendelian factors. This non-additive interaction of the genes is designated as 'epistacy' by Fisher [1918].

We shall consider in this section the genetical variance in relation to the three fibre properties and the appropriate method for the evaluation of the various genetical factors.

There are three parent strains, Cwn 520, Bani and Malvi. The first question which arises is : Which of these varieties gives the best results on crossing ? If **A**, **B** and **C** represent the set of genes in the parent strains, responsible for fineness, then a comparison* such as

$$(2\mathbf{AA}+\mathbf{AB}+\mathbf{AC})-(2\mathbf{BB}+\mathbf{BC}+\mathbf{AB})$$

* These formulæ were kindly suggested to one of us (R. S. K.) by Prof. R. A. Fisher, F.R.S., during his visit to India (January 1938).

will enable us to find out whether **A** is better than **B** or *vice versa*, while the variance contributed by this factor would be $[(2\mathbf{AA}+\mathbf{AB}+\mathbf{AC})-(2\mathbf{BB}+\mathbf{AB}+\mathbf{BC})]^2 \div 200$. We are now left with the third variety **C** which can be compared with the average effect of **A** and **B**. This is given by

$(4\mathbf{CC}+\mathbf{AC}+\mathbf{BC})-(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{AB})$, while the variance contributed by this factor is given by

$$[(4\mathbf{CC}+\mathbf{AC}+\mathbf{BC})-(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{AB})]^2 \div 600.$$

These two factors may be designated as 'genetic'.

In the present investigation fibre tests were made on 20 plants for each of the three parent strains and their first cross progenies, consequently, **AA**, **BB**, etc. represent the totals of 20 tests. The divisor for calculating the variance due to each factor is obtained by multiplying the sum of squares of the coefficients of **AA**, **BB**, etc. by 20. Thus the figures 200 and 600 are calculated as follows :—

$$(2^2+1+2^2+1)\times 20=10\times 20=200.$$

$$(4^2+1+1+2^2+2^2+2^2)\times 20=30\times 20=600.$$

In addition, we can compare the performance of the three parent strains with their F_1s ; this may be done by evaluating the expression

$$\mathbf{AA}+\mathbf{BB}-2\mathbf{AB},$$

i.e., double the value of each cross is compared with the sum of the performance of the two parent lines. If this expression yields a negative result, it is heterosis or hybrid vigour. In some species and in some characters it may happen that these comparisons give predominantly negative results ; in such cases their total contribution constitutes a single comparison for heterosis, or as it is sometime called 'dominance bias.' In the present example this effect is measured by

$$\begin{array}{r}\mathbf{AA}+\mathbf{BB}-2\mathbf{AB}\\ +\mathbf{AA}+\mathbf{CC}-2\mathbf{AC}\\ +\mathbf{BB}+\mathbf{CC}-2\mathbf{BC}\end{array}$$

and the variance contributed by this factor is obtained by dividing the square of this value by 480.

The figure $480=2^2\times 6\times 20$, since the above expression can be put in the form $(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{CC}-2\mathbf{AB}-2\mathbf{AC}-2\mathbf{BC})$

Now the only other genetical factor left is the manner in which interaction takes place between the different genes. This is spoken of as 'epistacy'. The three factors, which contribute to it, are

$$\begin{array}{l}\mathbf{AA}+2\mathbf{BC},\\ \mathbf{BB}+2\mathbf{AC},\\ \mathbf{CC}+2\mathbf{AB},\end{array}$$

and the sum of squares contributed by the two degrees of freedom corresponding to epistacy are

$$[(\mathbf{AA}+2\mathbf{BC})^2+(\mathbf{BB}+2\mathbf{AC})^2+(\mathbf{CC}+2\mathbf{AB})]^2\div 100$$
$$-[\mathbf{AA}+\mathbf{BB}+\mathbf{CC}+2\,(\mathbf{AB}+\mathbf{AC}+\mathbf{BC})]^2\div 300$$

The divisors 100 and 300 are obtained as follows :—

$$(1+2^2)\times 20=5\times 20=100$$

$$(1+1+1+2^2+2^2+2^2)\times 20=15\times 20=300$$

We can consequently divide the five degrees of freedom for varieties as shown in Table VIII.

TABLE VIII

Genetical factors ; fibre-weight per unit length

	D. F.	S. S.	M. S.	
Genetic	2	1·697043	0·84852**	Significant ($P=0·01$)
Epistatic	2	0·056920	0·02846	Non-significant
Heterosis	1	0·000404	0·000404	Do.
	5	1·754367		

Thus all the genetical variation is explained by the two degrees of freedom set apart for 'genetic', the contribution of the other two factors, epistacy and heterosis being entirely non-significant. We shall, therefore, concentrate our attention on this factor only. Since there are three parent strains, the two degrees of freedom can be further broken up into single degrees of freedom in three ways :

	D. F.	Variance	
(*a*) **A** *vs.* **B**	1	1·077512**	Significant ($P=0·01$)
C *vs.* **A** and **B**	1	0·619531**	Significant ($P=0·01$)
Total .		1·697043	
(*b*) **A** *vs.* **C**	1	0·026450	Non-significant
B *vs.* **A** and **C**	1	1·670593**	Significant ($P=0·01$)
Total .		1·697043	
(*c*) **B** *vs.* **C**	1	1·441602**	Significant ($P=0·01$)
A *vs.* **B** and **C**	1	0·255441	Non-significant
Total .		1·697043	

The results show that out of the three varieties Bani not only possesses distinctly lower fibre-weight per unit length, but also its crosses with either of the other two varieties are finer than the other cross. It is further interesting to note that the same conclusions apply to Bani with respect to fibre-length and fibre-maturity. Thus, Bani is the most satisfactory among these three varieties for producing crosses which should combine good staple length with fineness and maturity of hair. As regards the other two cottons analysis shows that there is nothing much to choose between them in this respect.

The analysis of genetical factors for percentage of mature hairs and mean fibre-length is given in Tables IX and X.

TABLE IX

Genetical factors ; percentage of mature hairs

	D. F.	S. S.	M. S.	
Genetic	2	411·01	205·51*	Significant ($P=0·05$)
Epistatic	2	215·23	107·62	Non-significant
Heterosis	1	213·33	213·33*	Significant ($P=0·05$)
		839·57		

TABLE X

Genetical factors, mean fibre-length

	D. F.	S. S.	M. S.	
Genetic	2	1·77064	0·88532**	Significant ($P=0·01$)
Epistatic	2	0·01441	0·00721	Non-significant
Heterosis	1	0·11470	0·11470**	Significant ($P=0·01$)
		1·89975		

It will be noticed that both for fibre-maturity and length, in addition to genetic comparison, heterosis is also significant, showing that the hybrids possess a tendency to produce fibres which are on the average maturer and longer than those in the parent strains. It is interesting to note that for all the three fibre properties studied in this investigation the effect of epistacy is small and non-significant. We may, therefore, conclude that the major portion of genetic variation is capable of being explained by the direct additive effect of the genes.

IV. FURTHER STUDY OF HETEROSIS

In the preceding section we found definite evidence for the existence of heterosis with respect to percentage of mature hairs and fibre-length. We shall now study this point in greater detail. If we represent the three parent strains, Malvi, Bani and Cwn 520 by M, B and C, we can denote the various crosses as under :—

Cross	Symbol
Malvi × Bani	$F_{1\ M \times B}$
Cwn 520 × Malvi	$F_{1\ C \times M}$
Cwn 520 × Bani	$F_{1\ C \times B}$

The average of the two parent strains may be indicated as A ; thus $A_{M \times B}$ with respect to any character would represent the average value of the two parent strains M and B.

Now, when two parent strains are crossed, there are in general three possibilities with respect to any measurable character :—

(1) The hybrid may be greater than the lower parent, but lower than the average of the two parents.

(2) It may be greater than the average of the two parents, but lower than the higher parent.

(3) It may be greater than either of the two parents. The last case is generally spoken of as heterosis or hybrid vigour.

Comparisons made along the lines indicated above are given in Tables XI and XII. We will first consider fibre-maturity.

TABLE XI

Heterosis in fibre-maturity

Malvi × Bani	$F_1\ \text{M}\times\text{B}$—M	$=2\cdot7\pm2\cdot15$	Non-significant
	$F_1\ \text{M}\times\text{B}$—B	$=-0\cdot7\pm2\cdot15$	Non-significant
	$F_1\ \text{M}\times\text{B}$—A $\text{M}\times\text{B}$	$=1\cdot0\pm1\cdot86$	Non-significant
Cwn 520 × Bani	$F_1\ \text{C}\times\text{B}$—B	$=3\cdot2\pm2\cdot15$	Non-significant
	$F_1\ \text{C}\times\text{B}$—C	$=8\cdot2\pm2\cdot15$	Significant
	$F_1\ \text{C}\times\text{B}$—A $\text{C}\times\text{B}$	$=5\cdot7\pm1\cdot86$	Significant
Cwn 520 × Malvi	$F_1\ \text{C}\times\text{M}$—M	$=0\cdot06\pm2\cdot15$	Non-significant
	$F_1\ \text{C}\times\text{M}$—C	$=2\cdot2\pm2\cdot15$	Non-significant
	$F_1\ \text{C}\times\text{M}$—A $\text{C}\times\text{M}$	$=1\cdot4\pm1\cdot86$	Non-significant

We obtain some interesting results from Table XI. When Malvi and Cwn 520 are each crossed with Bani, we get two F_1s. Of these, $F_1\ \text{M}\times\text{B}$ gives a higher percentage of mature hairs than the average of the two strains, but the increment is non-significant. On the other hand, the cross $F_1\ \text{C}\times\text{B}$ gives a higher percentage of mature hairs than either of the two parents, but the increase over the higher parent is non-significant.

The third cross $F_1\ \text{C}\times\text{B}$, like $F_1\ \text{M}\times\text{B}$, is not significantly different from the average of the two parent strains in respect of fibre-maturity. Thus, the average heterosis described in the previous section is due mainly to the cross between Cwn 520 and Bani. The same conclusion is obtained if we adopt the more general definition of heterosis and measure it by comparing twice the value of each cross with the sum of the values for the two parent lines.

We will now consider mean fibre-length.

TABLE XII

Heterosis in mean fibre-length

Malvi × Bani	$F_1\ \text{M}\times\text{B}$—M	$=0\cdot22\pm0\cdot025$	Significant
	$F_1\ \text{M}\times\text{B}$—B	$=-0\cdot04\pm0\cdot025$	Non-significant
	$F_1\ \text{M}\times\text{B}$—A $\text{M}\times\text{B}$	$=-0\cdot09\pm0\cdot022$	Significant
Cwn 520 × Bani	$F_1\ \text{C}\times\text{B}$—B	$=-0\cdot13\pm0\cdot025$	Significant
	$F_1\ \text{C}\times\text{B}$—C	$=0\cdot22\pm0\cdot025$	Significant
	$F_1\ \text{C}\times\text{B}$—A $\text{C}\times\text{B}$	$=0\cdot04\pm0\cdot022$	Non-significant
Cwn 520 × Malvi	$F_1\ \text{C}\times\text{M}$—M	$=0\cdot01\pm0\cdot025$	Non-significant
	$F_1\ \text{C}\times\text{M}$—C	$=0\cdot10\pm0\cdot025$	Significant
	$F_1\ \text{C}\times\text{M}$—A $\text{C}\times\text{M}$	$=0\cdot06\pm0\cdot022$	Significant

It will be seen from Table XII that none of the crosses gives significantly higher length than both the parent strains, though in each case the cross is significantly longer than the lower parent, while in two cases, namely $F_{1\ M\times B}$ and $F_{1\ C\times M}$ the mean length of the cross is not significantly different from that of the higher parent. There is thus evidence of a pooling of hereditary factors with the result that the combined effect is better than that which either can produce alone. This is confirmed by calculating heterosis from the general equation involving both the parent lines :—

$M+B-2\,F_{1\ M\times B} = -0\cdot086\pm0\cdot018$ . . . . Significant
$B+C-2\,F_{1\ B\times C} = -0\cdot046\pm0\cdot018$ . . . . Significant
$M+C-2\,F_{1\ M\times C} = -0\cdot053\pm0\cdot018$ . . . . Significant

Thus all the three crosses show evidence of hybrid vigour although it is more pronounced for the two crosses, $F_{1\ M\times B}$ and $F_{1\ M\times C}$, for which the negative differences are significant even for one per cent point.

V. Inter-relation of fibre-weight, fibre-maturity and fibre-length

Table XIII shows the result of applying analysis of variance and covariance to the three fibre properties studied in this investigation with a view to finding out the inter-relationship between them.

Table XIII

Inter-relationship between fibre-weight, fibre-maturity and fibre-length

	D. F.	r_{mw}	r_{ml}	r_{lw}
Varieties	4	—0·6092	0·7313	—0·8829*
Blocks	8	—0·1772	—0·1298	—0·2179
Plot-to-plot	44	0·4624**	0·1861	—0·3531*
Plant-to-plant	59	0·5198**	0·2689	—0·1096

The following conclusions are drawn from Table XIII :—

(*1*) *Between fibre-maturity and fibre-weight.*—The correlation between plants within the same plot is highly significant, indicating that, regardless of any variety, samples with high fibre-maturity are usually associated with high fibre-weight per unit length or, in other words, mature fibres are generally coarser for all varieties of cotton. The correlation is $+0\cdot520$, which agrees fairly well with the value $+0\cdot595$ found by Gulati and Ahmad [1935] for the 32 Indian cottons studied by them.

(*2*) *Between fibre-length and fibre-weight.*—The correlation for varieties is significant, i.e. cottons having long staple usually have low fibre-weight per unit length. This relationship, however, need not necessarily hold good for strains belonging to the same variety, for when the effect of varieties is removed, the correlation $-0\cdot1096$ for plants within the same plot is small and non-significant. This shows the existence of differential response among different varieties in this respect. This confirms the results of an earlier

investigation on cottons of different botanical species carried by Iyengar and Turner [1930]. They found that while among the *hirsutum* cottons, fibres of longer length generally possessed low fibre-weight per inch, the fibres of *herbaceum*, *neglectum* and *indicum* cottons do not generally show any such change of fibre-weight with fibre-length.

SUMMARY

This paper describes the results of an investigation undertaken with the object of studying the inheritance of three fibre properties, namely mean fibre-length, fibre-weight per unit length and fibre-maturity, which are known to have a considerable effect on the quality of yarn spun from a cotton. The tests were made on samples of three parent strans, namely Cwn 520, Bani and Malvi and their F_1s grown in a randomised block experiment in the same year at the Institute of Plant Industry, Indore.

From the preliminary analysis of variance it is found that the major portion of the observed variation is due to varieties and is of genetical nature, the variance due to blocks being small and non-significant. In order to study this genetical variation in greater detail, the variance for varieties was split up into three parts representing (1) genetic, (2) epistacy and (3) heterosis. Further analysis showed that for fibre-weight per unit length, greater part of the variation is of genetic origin, the effect of other two factors—epistacy and heterosis—being non-significant. For fibre-maturity and fibre-length, however, heterosis, in addition to genetic comparisons, is also found to be significant, showing that the hybrids possess the tendency to produce, on the average, larger number of mature and longer fibres than the parent strains. Further study of heterosis indicated that the cross Cwn 520 × Bani gave significantly higher maturity than the mean of the parents, while in the other two crosses, although the maturity values were higher than the mean of the two parents the differences were not significant. As against it, all the hybrids showed that there is evidence of the existence of heterosis in fibre-length, for each one of them gave significantly higher mean fibre-length than the mean of the two parents.

In order to find out which variety gives the best results on crossing, a comparison study was made for the parents and their first cross progenies. If **A**, **B** and **C** represent a set of genes, characteristic of the parent strains, in respect of any one fibre character, the expression

$$(2\mathbf{AA} + \mathbf{AB} + \mathbf{AC}) - (2\mathbf{BB} + \mathbf{BC} + \mathbf{AB})$$

would enable us to say whether or not **A** is better than **B**. On applying this method to the three fibre properties it was found that Bani gave significantly higher fibre-length and fibre-maturity, and lower fibre-weight than the other two varieties. Among the two crosses of Bani, the one with Malvi is longer and finer than that with Cwn 520. It is suggested that Bani should be crossed with other suitable varieties to find out where the shuffling of useful characters occurs to the best advantage for the improvement of quality.

By the application of analysis of covariance two interesting correlations which confirm the previous findings were obtained :—

(*1*) *Correlation between fibre-maturity and fibre-weight.*—The correlation for plants within the same plot is positive and significant, indicating that, regardless of any variety, mature fibres are generally coarser.

(2) *Correlation between fibre-length and fibre-weight per unit length.*—The correlation for varieties is negative and significant, but for plants within the same plot, it is non-significant. This shows that fibres of longer length of all cottons do not generally give less fibre-weight per unit length, indicating that a differential response may exist among varieties in this respect.

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APPENDIX

Experimental data for the three fibre-properties

Table A

Fibre-weight per unit length ($10^{-6}\frac{gm.}{cm.}$)

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520	*840-12* 2·79	*840-10* 2·23	*840-7* 2·28	*840-1* 2·11	*840-3* 2·34	*840-4* 2·67	*840-4* 2·40	*840-7* 2·42	*840-3* 2·63	*840-13* 2·05
	840-18 3·02	*840-17* 2·63	*840-15* 2·43	*840-9* 2·69	*840-8* 2·48	*840-16* 2·44	*840-12* 2·53	*840-19* 2·18	*840-12* 2·78	*840-18* 2·63
Bani	*838-2* 2·39	*838-6* 2·20	*839-10* 2·19	*838-2* 2·36	*838-3* 2·11	*838-1* 1·88	*839-11* 1·84	*839-3* 2·13	*839-15* 2·29	*839-3* 2·37
	838-10 2·05	*838-16* 2·13	*839-20* 2·15	*838-10* 2·45	*838-13* 2·22	*838-13* 2·50	*839-14* 2·60	*839-19* 2·37	*839-17* 2·16	*839-8* 1·95
Malvi	*835-4* 2·64	*836-14* 2·46	*835-9* 2·45	*835-5* 2·78	*837-7* 2·56	*835-1* 2·81	*835-11* 2·34	*837-1* 2·47	*835-5* 2·56	*836-6* 2·85
	835-5 2·50	*836-20* 2·56	*835-12* 2·40	*835-16* 2·77	*837-14* 2·34	*835-11* 2·50	*835-17* 2·54	*837-6* 2·67	*835-18* 2·67	*836-10* 2·43
Cwn 520 × Malvi	*860-7* 2·59	*856-11* 2·56	*858-6* 2·23	*855-2* 2·73	*854-8* 2·24	*852-3* 2·81	*857-9* 2·49	*851-6* 2·67	*853-1* 2·69	*859-4* 2·60
	860-10 2·75	*856-13* 2·39	*858-11* 2·88	*855-8* 2·20	*854-18* 2·12	*852-9* 2·77	*857-15* 2·49	*851-14* 2·52	*853-17* 2·41	*859-9* 2·71
Bani × Malvi	*862-6* 2·14	*867-12* 2·11	*866-11* 2·50	*861-4* 1·99	*869-8* 2·64	*870-2* 2·72	*868-4* 2·78	*865-14* 2·37	*863-14* 2·20	*864-2* 2·36
	862-9 2·35	*867-17* 2·02	*866-13* 2·39	*861-20* 2·25	*869-18* 2·22	*870-13* 2·51	*868-16* 2·39	*865-18* 2·21	*863-19* 2·56	*864-20* 2·24
Cwn 520 × Bani	*847-1* 2·04	*849-17* 2·40	*845-16* 2·58	*842-5* 2·30	*848-7* 2·62	*850-5* 2·44	*841-2* 2·56	*844-3* 2·49	*846-7* 2·19	*843-5* 2·11
	847-11 2·46	*849-19* 2·35	*845-19* 2·49	*842-15* 2·31	*848-19* 2·31	*850-20* 2·49	*841-13* 2·36	*844-6* 2·40	*846-8* 2·50	*843-15* 2·39

Figures in *italics* indicate the progeny and plant number

Table B

Percentage of mature hairs

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520 . .	*840-12* 80 *840-18* 79	*840-10* 63 *840-17* 63	*840-7* 67 *840-15* 62	*840-1* 41 *840-9* 66	*840-3* 72 *840-8* 70	*840-4* 76 *840-16* 66	*840-4* 75 *840-12* 71	*840-7* 61 *840-19* 60	*840-3* 74 *840-12* 77	*840-13* 54 *840-18* 75
Bani . .	*838-7* 78 *838-10* 74	*838-6* 75 *838-16* 71	*839-10* 73 *839-20* 69	*838-9* 77 *838-10* 85	*832-3* 74 *838-13* 77	*838-1* 75 *838-13* 60	*839-11* 49 *839-14* 68	*839-3* 70 *839-19* 79	*839-15* 81 *839-17* 80	*839-3* 72 *839-8* 65
Malvi . .	*835-4* 69 *835-5* 67	*836-14* 61 *836-20* 72	*835-9* 68 *835-12* 58	*835-5* 65 *835-16* 77	*837-7* 79 *837-14* 71	*835-1* 68 *835-11* 70	*835-11* 60 *835-17* 69	*837-1* 77 *837-6* 73	*835-5* 72 *835-18* 67	*836-6* 76 *836-10* 65
Cwn 520 × Malvi	*860-7* 69 *860-10* 60	*856-11* 66 *856-13* 68	*858-6* 75 *858-11* 69	*855-2* 74 *855-8* 63	*854-8* 78 *854-18* 68	*852-3* 78 *852-9* 67	*857-9* 58 *857-15* 72	*851-6* 74 *851-14* 72	*853-1* 70 *853-17* 70	*859-4* 71 *859-9* 74
Bani × Malvi .	*862-6* 71 *862-9* 76	*867-12* 73 *867-17* 76	*866-11* 71 *866-13* 72	*861-4* 64 *861-20* 72	*869-8* 75 *869-18* 67	*870-2* 70 *870-13* 75	*868-4* 72 *868-16* 67	*865-14* 73 *865-18* 72	*863-14* 70 *863-19* 74	*864-2* 73 *864-20* 74
Cwn 520 × Bani	*847-1* 64 *847-11* 78	*849-17* 85 *849-19* 80	*845-16* 84 *845-19* 80	*842-5* 76 *842-15* 66	*848-7* 87 *848-19* 68	*850-5* 67 *850-20* 70	*841-2* 86 *841-13* 70	*844-3* 79 *844-6* 71	*846-7* 69 *846-8* 80	*843-5* 77 *843-15* 78

Figures in *italics* indicate the progeny and plant number

Table C

Fibre-length (cm.)

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520 . .	*840-12* 1·62 *840-18* 1·60	*840-10* 1·74 *840-17* 1·77	*840-7* 1·68 *840-15* 1·71	*840-1* 1·60 *840-9* 1·72	*840-3* 1·68 *840-8* 1·64	*840-4* 1·75 *840-16* 1·68	*840-4* 1·79 *840-12* 1·80	*840-7* 1·77 *840-19* 1·74	*840-3* 1·71 *840-12* 1·74	*840-13* 1·72 *840-18* 1·75
Bani . .	*838-2* 2·10 *838-10* 2·08	*838-6* 2·06 *838-16* 2·19	*839-10* 2·14 *839-20* 2·06	*838-2* 2·09 *838-10* 2·06	*838-3* 2·05 *838-13* 2·04	*838-1* 2·17 *838-13* 2·04	*839-11* 1·94 *839-14* 1·98	*839-3* 2·03 *839-19* 1·99	*839-15* 2·14 *839-17* 1·95	*839-3* 2·07 *839-8* 2·08
Malvi . .	*835-4* 1·78 *835-5* 1·66	*836-14* 1·71 *836-20* 1·81	*835-9* 1·82 *835-12* 1·69	*835-5* 1·72 *835-16* 1·81	*837-7* 1·87 *837-14* 1·91	*835-1* 1·76 *835-11* 1·86	*835-11* 1·88 *835-17* 1·84	*837-1* 1·89 *837-6* 1·90	*835-5* 1·76 *835-18* 1·85	*836-6* 1·73 *836-10* 1·75
Cwn 520 × Malvi	*860-7* 1·67 *860-10* 1·69	*856-11* 1·74 *856-13* 1·88	*858-6* 1·92 *858-11* 1·70	*855-2* 1·80 *855-8* 1·87	*854-8* 1·91 *854-18* 1·89	*852-3* 1·79 *852-9* 1·82	*857-9* 1·83 *859-15* 1·83	*851-6* 1·89 *851-14* 1·88	*853-1* 1·78 *853-17* 1·82	*859-4* 1·78 *859-9* 1·68
Bani × Malvi .	*862-6* 1·94 *862-9* 1·97	*867-12* 2·00 *867-17* 2·13	*866-11* 2·03 *866-13* 2·01	*861-4* 1·99 *861-20* 2·00	*869-8* 2·05 *869-18* 2·01	*870-2* 1·89 *870-13* 2·01	*868-4* 2·09 *868-16* 2·02	*865-14* 2·00 *865-18* 2·15	*863-14* 2·08 *863-19* 1·91	*864-2* 2·07 *864-20* 2·00
Cwn 520 × Bani	*847-1* 1·82 *847-11* 1·85	*849-17* 1·97 *849-19* 1·94	*845-16* 1·91 *845-19* 1·78	*842-5* 1·94 *842-15* 1·84	*848-7* 1·74 *848-19* 1·85	*850-5* 2·02 *850-20* 2·00	*841-2* 2·01 *841-13* 1·97	*844-3* 2·05 *844-6* 1·94	*846-7* 1·98 *846-8* 2·02	*843-5* 1·96 *843-15* 2·07

Figures in *italics* indicate the progeny and plant number

STUDIES ON KUMAUN HILL SOILS *

I. SOIL SURVEY AT THE GOVERNMENT ORCHARD, CHAUBATTIA: FORMATION OF GENETIC GROUPS

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(With Plate XLV)

I. General

THE Hills of Kumaun division forming a part of the southern outer spurs of the Himalayas comprise three districts of the United Provinces—Almora, Garhwal and Naini Tal. Beginning from the snowy range, this division consists of a succession of ridges of decreasing heights southwardly. These hills contain very little level land. Cereal crops are cultivated on terraced hill slopes, particularly where factors such as height, situation and irrigation facilities are favourable. In addition to these crops, the suitability of some of the tracts for fruit cultivation has been established with the result that a very large number of fruit orchards have developed in recent years on commercial lines for temperate fruits like apples, pears, peaches, cherries, plums, strawberries, etc. No quantitative data are, however, available on the suitability of the different types of hill soils for different fruit trees, nor are there any quantitative data correlating the soil conditions with the incidence of diseases and pests. The importance of knowing the soils intimately is felt all the more as, these hill soils being mostly primary in origin, a knowledge of the nature of the major soil-forming processes and development of the diverse soil types is a feature of fundamental importance to the fruit growers of these hills.

In India, no systematic work on hill soils, specially from a pedogenic point of view, has been reported so far. The work reported by Mann [1933] on the tea soils of Assam hills was merely an analytical evaluation of those soils in regard to their crop-bearing capacity. The applied science of pedology is still in its infancy in India. Credit must therefore go to Basu and Sirur [1938] for the first and the most systematic pedogenic study of the canal soils of Bombay. Pedological studies for the mountain soils in other countries too have not been at all as numerous as for plain soils. Zokharov [1927] in his

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remarkable treatise on pedology was the first to recognize the following four types of soil formations in the mountains : Mountain steppe, mountain forest, mountain meadow and mountain tundra soils. Mountain forest soils which are of interest to us were divided into four groups, depending on the colour of the soils. But analytical figures revealed that the differences were not fundamental, and all the groups were podsolic. Various other investigations, notably by Neustruev [1915], Akimzev [1930] and Throp [1931], have dealt with the vertical zonality of the mountain soils as the counterpart of the horizontal zonality of the soils in the plains. Alpine soils discussed by Jenny [1930] fit in well with Zokharov's mountain meadow soils. Besides these, considerable information is available on the general nature of the mountain soils.

The investigations reported by Jenny [1926], Vilenski [1930], Robinson and Wasowicz [1935], to name only a few, illustrate the development of mountain soils under varied conditions. Jenny [1926] has observed that 80 per cent of alpine soils developed on calcareous material are acidic. It is clear that although the general nature of hill soils is known, a detailed knowledge of the soil-forming processes and soil types under various topographical and geological conditions have not yet been thoroughly investigated. For instance it has been shown by Kellog [1936] that local soil variations may be considerable within the region of a particular soil zone in the plains, but this question has not however been investigated with reference to the hill soils.

In India and elsewhere hill soils have been studied in some detail from erosion point of view. But in most cases these investigations have been directed to elucidate the relationship between erodibility and forest vegetation. It is only in the U. S. A. that attempts are being made to study soil profiles in their relation to erodibility. In India considerable work, particularly in connection with afforestation policy and controlled grazing [Gorrie, 1937], has been done in the hills, but the nature of hill soils from the point of view of erodibility has nowhere been investigated. The observations made in the U. S. A. by Bennett [1926], Middleton [1932], Baver [1933], Lutz [1934] and Bouyoucos [1935] make it clear that the soil properties, such as structure, texture, plasticity, etc. are directly responsible for the high erodibility of some soils ; whereas Lowdermilk [1930] and Miller [1931] associate erodibility with definite soil types. The advantage of terracing hill slopes to decrease run-off and conserve soil moisture [Ramser, 1933] have been indicated ; but whether topographically immature hill soils, particularly those situated along steep slopes, can be profitably utilized by terracing have not been thoroughly investigated.

To elucidate these points a detailed soil survey of the Government Orchard at Chaubattia was thought to be highly desirable. Accordingly a scheme of survey was taken up about six years ago with the double object of :

(*i*) Studying the relationship between soil conditions and differential behaviour of various fruit trees, stock and varieties with a view to be able to advise with confidence the commercial orchardists of Kumaun on the planting of new orchards, or, if necessary, relaying of old orchards ; and (*ii*) ascertaining whether there is any clear-cut relationship between soil conditions and the incidence of diseases and pests.

The present contribution aims at recording the formation of soils at Chaubattia under unterraced natural conditions. Chaubattia is situated at 29½° N. Latitude and 79½° E. Longitude and the height above sea-level varies from 6,100 ft. to 6,900 ft. The soils studied lie on the northern face of the Chaubattia hills overlooking the distant perpetual snow-topped Himalayan ranges of Nanda Devi, Trisul and Nanda Kud.

TABLE I

Monthly weather record at Chaubattia

Month	Temperature (°F.)		Humidity per cent at 8 A.M.	Rainfall (in.)
	Maximum	Minimum		
January	49·35	37·42	87	4·64
February	50·56	37·32	83	3·56
March	65·25	49·58	55	0·08
April	74·18	56·83	49	0·08
May	76·90	70·22	69	1·82
June	72·88	61·00	81	11·40
July	71·52	62·00	98	19·38
August	72·13	61·42	95	14·50
September	73·00	58·76	91	1·22
October	68·96	53·28	76	0·40
November	59·30	42·57	76	..
December	59·34	42·90	79	..
		Total annual rainfall		57·08

HISTORY OF CHAUBATTIA

The Government Orchard at Chaubattia was started in the year 1870 with about 40 acres of land given to the growing of temperate fruits. Subsequently more lands were brought under cultivation and at present it consists of a cultivated area of 100 acres. The hill slopes for the greater part of the orchard have been terraced. Contour planting has been done in certain parts of the orchard after clearing the forest lands about the year 1924. The present contribution deals with this part of the orchard, where pedogenic processes have not been distorted by terracing operations. These slopes are always under grasses, and fruit cultivation is done by contour planting.

TABLE II

Soil temperature—monthly averages (soil type—brownish loam)

Month	Temperature (°C.)		
	4 in. depth	6 in. depth	12 in. depth
January	4·52	5·38	6·77
February	4·70	5·56	6·67
March	10·75	11·65	12·31
April	16·65	17·45	18·01
May	13·05	20·20	21·05
June	19·04	19·73	20·69
July	16·14	19·83	20·33
August	19·48	20·00	20·50
September	18·13	18·87	20·28
October	14·98	16·02	18·20
November	9·68	10·73	13·20
December	7·58	8·15	10·41

CLIMATE

No systematic meteorological records of Chaubattia are available prior to the year 1935. The records of maximum and minimum temperatures, humidity and rainfall for 1938, supposed to be one of the normal years, are given in Table I. Winter rains, accompanied sometimes with snow, are usually confined to the months of January and February. There are about two to three snow-falls every year and in some years rains start early in the month of December. The months of March, April, May, October and November are usually rainless. *Chota barsat* (local rainfall) in May heralds the advent of monsoon a month earlier, and July and August are the wettest months in the year. It is usual to find frost every morning from November till the middle of February, and in shady places a thick matting of this remains throughout the winter months. The maximum temperature of 85°F. is recorded in the month of May with a minimum temperature of 23°F. in the month of January. There are two rises every year in maximum temperatures. The highest rise is recorded before the monsoon and the second rise takes place after this

sometime in September. There are similarly two rises in soil temperatures before and after the monsoon.

During the monsoon, although the temperature of the sub-soil at a depth of one foot remains fairly constant, the surface soil experiences some minor fluctuations. With the advent of frost in the month of November the soil temperature goes down considerably and snow and rain keep the temperature at a low level till the end of February. The trend of the average soil temperatures at different depths will be clear from Table II.

Grass vegetation along hill slopes gets fully established after the light shower (*chota barsat*) in May and consequently the worst effect of heavy monsoonic downpour in July and August, sometimes 6 in. in a single day, are partly counteracted. This natural agency is not to a small degree responsible for the preservation of soil in these hill slopes in spite of intensive land utilization practices. But along steep slopes extremely deep erosion gullies have been formed on account of the indiscriminate destruction of forests for agricultural purposes. The southern slopes of these hills are on the average warmer, where some of the typical tropical plants like mangoes, guavas, etc. are grown with success.

Vegetation

The forest vegetation of the locality chiefly consists of different species of *Quercus* (oaks) and *Pinus longifolia*. The oak prefers a humid locality of undulating type, not very steep, while the pine thrives best in dry localities and grows even on mantle rock surfaces. Among the minor forest arboreal flora, mention may be made of the following: *Rhododendron arboreum* (Smith), *Pieris ovallfolia* (Don.), *Myrica sapids*, *Pyrus pashia* (B.Ham.), *Prunus puddum* (Roxb.), *Aesculus hippocastanum*, *Cedrus deodara* and *Cupressus* sp.

The undergrowth which is mostly confined to oak forest mainly consists of different species of the following genera :—*Rhubus*, *Cratagus*, *Herberis Daphne*, *Rosa moschata* (Mill), *Indigo-fera*, *Vibernum* and *Myrsine africana* L. There is very little, if any, undergrowth of importance under pine forest. Probably this is the reason for the local belief that an ideal site for an orchard is the locality where oak predominates and the site of a pine fores should be avoided as far as possible. It has been found that the depth of soil in a predominantly pine forest hardly reaches a foot, whereas brown and podsolic soil formations are usually met with in the oak forests.

The grasses and weeds met with in cleared forest lands belong to the following groups :—*Imperata cylindrica*, *Oenothera biennis*, *Oenothera rosea* (Sim.), *Oxalis* sp., *Imperata arundinacea* (Cyrill), *Paspalum* sp., *Andropogon contortus* L., *Cetraria glauca* (bean), *Ranunculus diffusus* (in the valleys), *Andropogon mycranthus* (Kuth), *Arundinella setosa* (Trin.), *Anthistriia anathera* (Nees).

It is interesting to note how each of these different species occurs under different soil conditions,. *Saccharum spontaneum* (*kans*) and *Imperata cylindrica* (*siroo*) usually prefer a soil containing little or no organic matter and with very loose sub-soil consistency. Therefore they are mostly found growing on ridges and seldom in lowlands. On the other hand, *Rhubus*, *Ranunculus*, *Ophiopogon*, *Pteris* (Bracken), *Reinwardtis*, *Berberis* and *Polygonum* prefer organic moist soils and shady places.

Geology

There are two main soil-forming rocks of importance in this locality, viz. garnetiferous biotite-schist and weathered granite gneiss*. Although on an average the analytical figures for these two types of rocks are not very different, the nature of the overlying soils, formed under more or less identical condition, is very dissimilar. Under the local conditions biotite as a parent material invariably produces heavier-textured soils than granite gneiss; the former is by far more easily influenced by soil genetic processes, as is evident from the fact that in the zones where both of these rocks occur together biotite appears to be considerably more disintegrated than granite. The weathered product of the former is sticky and brown, whereas that of granite is sandy, and yellowish brown, when wet and white when dry.

Garnetiferuous biotite schists form the parent material of the greater part of Chaubattia Orchard. At some places both biotite and granite appear to be present intimately mixed with each other. Biotite-muscovite-quartz schist, however, appears to be present at a few places in the orchard. Thus generally the soils might be taken to have been formed from igneous rocks.

II. Methods and procedure

A thorough survey of the Government Orchard at Chaubattia at points 100 ft. apart, both along and across the slopes, has been carried out. The present contribution deals with only unterraced soils and the results of the studies made in terraced soils will form the subject matter of a subsequent contribution. Pits were dug at the corresponding points of horizontal and vertical cross-lattices of the orchard map at regular distances of 100 ft. These pits were sufficiently broad for an observer to go inside and note horizon characteristics and each of the pits was dug up to the decomposing parent rock or up to impervious clay pan in typically clay profiles. In some cases, the clay pans were cut through; underlying the clay pan, it is usual to find the parent rock at different stages of decomposition. In one case, forming a pocket between two ridges, it was found that the clay pan had a depth of about 6 ft.

Observations in regard to the characteristics of each horizon, particularly colour, texture, structure, depth and hardness, were made *in situ*, and representative samples were obtained from each horizon for laboratory study. Owing mainly to their positions along the slopes, the soils under field conditions were found to have different moisture contents and, therefore, it was felt desirable to supplement these field observations with similar observations made in the laboratory under uniform and controlled conditions. The soil samples were, therefore, air-dried and studied under air-dried and moisture-saturated conditions. This undoubtedly afforded a fuller knowledge of the horizons than that based on observations in the field alone. So far we have examined 1224 horizon soils arising out of a total of 405 profiles. The complete mechanical, chemical, and physico-chemical analyses of such a large number of soils being out of the question, attempt was made to classify the soils according to their visual and textural characteristics. Accordingly all the above-mentioned 1224 soils were classified into groups

* Geological Survey of India—private communication.

depending on the following principal soil characteristics and their combinations :—

(1) Presence of micaceous sand
(2) Presence of quartzose sand
(3) Clay content and texture
(4) Colour

Each sample was analysed for :—

(*a*) Mechanical : coarse sand, fine sand, silt and clay.
(*b*) Chemical ; SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, moisture, loss on ignition, nitrogen, organic carbon, and
(*c*) Physico-chemical : *p*H and exchange acidity.

A large number of these samples were analysed for total P_2O_5 which was invariab'y found to be very low. In no case the amount of P_2O_5 present exceeded 0·05 per cent. Hence, the P_2O_5 content of these soils has not been included in the calculation of R_2O_3 figures. In some cases the clay fraction has been analysed for SiO_2, Al_2O_3 and Fe_2O_3.

Analytical methods

Two-millimetre samples were used for both mechanical and chemical analyses. Hydrochloric acid extract was prepared according to the directions of the British Agricultural Education Association [Wright, 1934]. Lime and magnesia were estimated volumetrically and the former was precipitated in acetic acid medium. For the estimation of nitrogen, Kjeldahl's method was followed after pre-treating the soils with water as suggested by Bal [1925]. The quinhydrone electrode method was adopted for the determination of *p*H values. Exchangeable acidity was determined by Kappens [1927] method. Organic carbon was estimated by Walkley and Black [1934] method with chromic acid. Clay fraction was dispersed by International method, and syphoned off to 8·6 cm. depth after 24 hours. Coagulation was effected by calcium chloride. The samples were analysed by usual fusion method for the determination of silica.

The analytical data only in regard to complete profiles are detailed in Tables III-XII.

III. Data and discussion

From the data obtained it is obvious that a large number of soils of the orchard according to expectation shows primary characteristics and forms fous distinct genetic types, viz. (1) Red loams, (2) Brown forest soils, (3) Podsol- and (4) Wiesenboden or meadow soils. Although, as has already been men tioned, all of these soils arise out of two parent rocks, yet their development into clear-cut genetic types is presumably due to differences in topographical conditions and weathering processes—chemical, physical and biochemical. Of course, instances of variations within each of the soil types are somewhat numerous. The atmospheric climate of the locality is within limits uniform, but it is clear that the soil climate will be different according to the topographical conditions, i.e. the slope gradient, situation and vegetation. It is, therefore, considered desirable to present the data separately for each of the genetic types enumerated above.

RED LOAMS

Three profiles under this group have been examined in detail and the visual characteristics have been studied for 20 more profiles. The visual characteristics of the horizons constituting each of these three typical profiles are briefly given below :—

Visual characteristics of red loam profiles

Profile No.	Depth of horizon	Horizon	Description
8 R 5 .	0—1 ft.	A	Grey ; micaceous ; organic ; loamy soil. Reddish when wet.
	1 ft.—3 ft. .	B	Sandy ; greyish yellow ; micaceous soil. More yellow when wet.
	3 ft.—4 ft. .	C	Sandy ; ash grey ; very light ; structureless soil. No change when wet.
14 R 5 .	0—6 in. . .	A	Brownish grey ; slightly organic ; loamy soil with plenty of undecomposed organic matter. Darkens slightly in colour when wet.
	6 in.—1 ft. 8 in.	B	Loamy ; reddish brown soil containing little humus. Deep red brown when wet.
	1 ft. 8 in.—3 ft. 9 in.		Loamy sand, yellowish brown soil. More yellow when wet.
	3 ft. 9 in.—5 ft.	C	Loamy ; ash grey ; slightly micaceous soil of hydrogenic nature. More green when wet.
X 13 Y 33 .	0—6 in. . .	A	Granular ; grey ; loamy ; when wet reddish grey ; contains stones and undecomposed organic matter.
	6 in.—10 in. .	B	Yellowish ; micaceous ; loamy ; when wet reddish yellow. Contains stones (mica).
	10 in.—2 ft. .	C	Micaceous sandy loam ; yellowish ; more yellow when wet.

The analytical data for each of these profiles are given in Tables III and IV.

TABLE III

Analytical results of red loams (chemical determinations)

Name of profile	Depth	Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter (in strong HCl) (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	Mgo (per cent)	CaO (per cent)
13 R 5	0—1 ft. . .	2·19	9·09	3·94	0·274	14·4	7·0	76·8	4·00	6·17	10·17	0·62	0·36
	1 ft.—3 ft. .	0·71	2·60	0·51	0·062	8·22	6·7	86·18	3·44	5·57	9·01	0·40	0·091
	3 ft.—4 ft. .	0·56	2·00	0·23	0·055	4·2	7·1	90·9	1·92	3·52	5·44	0·18	0·014
14 R 5	0—6 in. . .	2·13	8·66	3·35	0·183	18·3	6·4	76·3	4·64	6·91	11·55	0·60	0·21
	6 in.—1 ft. 8 in.	2·01	6·57	1·77	0·118	15·0	5·7	77·9	4·72	7·79	12·51	0·50	0·049
	1 ft. 8 in.—3 ft. 9 in.	0·91	2·71	0·241	0·053	4·53	5·5	85·4	3·84	6·01	9·85	0·44	0·00
	3 ft. 9 in.—5 ft. 9 in.	1·53	2·75	0·220	0·048	4·90	5·3	89·9	2·40	2·70	5·10	0·16	0·035
X13 Y 33	0—6 in. . .	2·26	7·90	3·12	0·22	14·2	6·8	76·08	4·23	8·11	12·34	0·190	0·210
	6 in.—10 in. .	1·44	4·25	1·13	0·10	11·3	6·2	81·17	3·73	7·70	11·43	0·69	0·070
	10 in.—2 ft. .	1·30	3·57	0·47	0·07	6·7	5·8	81·52	3·55	8·52	12·07	0·08	0·007

TABLE IV

Analytical results of red loams (mechanical determinations)

(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Exchange H m. e. (per cent)
13 R 5	0—1 ft. . .	19·40	41·43	18·63	15·50	0·088
	1 ft.—3 ft. .	19·63	68·09	7·37	6·68	0·35
	3 ft.—4 ft. .	21·5	62·8	9·9	6·5	0·88
14 R 5	0—6 in. . .	17·03	31·55	27·45	20·68	0·18
	6 in.—1 ft. 8 in.	15·78	31·57	28·80	23·48	3·76
	1 ft. 8 in.—3 ft. 9 in.	40·89	38·42	11·40	9·65	4·28
	3 ft. 9 in.—5 ft.	28·7	34·6	19·6	17·6	8·13
X 13 Y 33	0—6 in. . .	13·42	31·29	31·65	15·65	..
	6 in.—10 in. .	28·26	35·41	18·30	13·60	0·088
	10 in.—2 ft. .	29·95	40·27	13·65	12·75	1·40

From the results it is evident that these red loams represent the intermediate stage between lateritic and podsolic developments. Although the analytical figures show eluviation of silica relative to sesquioxides which indicates a lateritic tendency, yet considerable accumulation of organic matter in the A-horizons coupled with the acidity of the soil and humid, temperate climate tends to make the soil podsolic. On a joint consideration, therefore, of the sesquioxides in the different horizons and the comparatively low organic matter content in the sub-soils, it becomes apparent that these soil types belong to recognised red loams—intermediate between podsolic and lateritic formations. The bases, particularly silica, are relatively poor in the surface soils and seem to have been leached down to the lower horizons as against sesquioxides that decrease downwards. The position with regard to lime and magnesia is slightly different. The grass vegetation brings up some of the leached bases from lower horizons, and whatever escapes this natural enriching process, is washed away from the profile as a whole. The high C/N ratio in the A-horizons is partly due to undecomposed organic matter.

These profiles which lie mostly along slopes of hills or along ridges are generally sandy in nature. The soils, owing to the open sub-soil texture, allow free drainage and it is usual to find them dry in a few hours after a heavy rainfall. The oxidation of organic matter under these conditions is very pronounced. On analysis the surface soils are found to contain a fairly high

percentage of organic matter ; but the fact that, on moistening, the soils assum a somewhat reddish grey colour instead of dark grey shows that the humus has undergone considerable mineralization. As regards Fe_2O it may be concluded that in the sub-soils local conditions favour a higher degree of hydration than that in the surface horizon—the colour of the sub-soil being brownish yellow whereas that of the top-soils is reddish grey.

The soils of this nature are, however, not very common under the conditions of the locality, and they occur at places which receive maximum solar radiation and are always dry owing to their situation on the ridges of slopes.

In the International classification of soils the position of red loam is not clearly defined. Harrassowitz [1930] pointed out that red and yellow loams are related soil types. Marbut [1928] has observed that yellow colour is found only in sandy profiles, whereas profiles having heavy texture are red or reddish. The data from the U. S. Bureau of Soils on red and yellow soils [Joffe, 1936] definitely show podsolic tendencies. The soils studied by us more or less resemble these red and yellow Soils encountered in the United States of America. At the present stage of knowledge it is not, however, desirable to separate red and yellow loams into different groups [Robinson, 1932]. The yellow soils studied by us have, therefore, been classified as red loams.

The trend of the changes in the insoluble residue of HCl-extract and sesquioxides with depth indicates that these soils have certain red loam characteristics, whereas the nature of the variations in the pH value and exchangeable acidity tends to favour the classification of these as brown earths. It is thus apparent that soils similar to these form border-line cases between red loams and brown earths.

Brown forest soils

Seventeen profiles under this group have been analysed in detail and visual characters studied for 200 more profiles. The visual characteristics of the horizons constituting each of five typical profiles are given below :—

Visual characters of grey brown forest soils

Profile No.	Horizon	Depth	Description
X5 Y20	A	0—8 in.	Granular ; brownish grey ; clayey ; organic soil containing undecomposed organic matter. Darkens when wet.
	B	8 in.—1 ft. 7 in.	Brownish ; loam with mica bits. More brown when wet.
	C	1 ft. 7 in.—3 ft. 1 in.	Sandy loam ; brownish ; micaceous ; stony soil. More brown when wet.
X7 Y22 (Plate XLV, fig. 1)	A	0—1 ft.	Deep grey ; highly organic ; finely granular clayey soil containing plenty of roots. Darkens when wet.

FIG. 1. Brown forest soil (X 7 Y 22)

FIG. 2. Podsol profile (mixed No. IV)

Visual characters of grey brown forest soils—contd.

Profile No.	Horizon	Depth	Description
X7 Y22 (Plate XLV, fig. 1)	B	1 ft.—2 ft. 6 in.	Brownish; clayey; micaceous; slightly organic soils with roots. Dark brown when wet.
	C	2 ft. 6 in.—3 ft. 10 in.	Loam; yellowish soil containing mica bits. Brownish when wet.
X16 Y8	A	0—8 in. . .	Brownish grey; granular; slightly organic; clayey soil. Dark brownish grey when wet.
	B	8 in.—2 ft. .	Brownish clayey soil. More brown when wet.
	C	2 ft.—4 ft. .	Sandy loam; brownish; micaceous; stony soil. More brown when wet.
X14 Y23	A	0—5 in. . .	Organic; granular; micaceous; dark grey, containing mica. Darker when wet. Contains undecomposed organic matter.
	B	5 in.—8 in. .	Brownish yellow—mostly rock material—loamy soil. More brown when wet.
	C	8 in.—2 ft. 6 in.	Yellow decomposing rock material mostly mica. Deep yellow when wet.
X25 Y19	A	0—1 ft. . .	Granular, dark grey, darker when wet. Contains roots and charcoal.
	B	1 ft.—1 ft. 8 in.	Yellowish, granular, clay, contains sand. A little grey when wet.
	B_2+C	1 ft. 8 in.—3 ft. 11 in.	Hard clay, whitish grey, contains bluish hard mass at places, whitish incrustations, reddens a little when wet.

The analytical figures for the above profiles are given in Tables V and VI.

TABLE V

Analytical results of brown forest soils (chemical determinations)

Name of profile	Depth	Horizon	Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter (in strong HCl) (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	MgO (per cent)	CaO (per cent)
X5 Y20	0—8 in.	A	2·71	3·33	2·73	0·15	18·20	6·2	77·50	3·65	11·42	15·07	0·71	0·238
	8 in.—1 ft. 7 in.	B	2·04	3·56	0·51	0·06	8·47	5·8	77·82	4·21	10·38	14·59	1·16	0·119
	1 ft. 7 in.—3 ft. 1 in.	C	1·07	2·43	0·25	0·03	8·48	6·4	86·11	3·19	6·01	9·20	0·51	0·088
X7 Y22	0—1 ft.	A	3·48	9·51	3·43	0·27	12·70	6·3	74·68	3·99	7·42	11·41	0·43	0·294
	1 ft.—2 ft. 6 in.	B	2·72	5·05	1·25	0·11	11·36	6·1	76·99	4·74	8·61	13·35	0·25	0·253
	2 ft. 6 in.—3 ft.	C	1·32	2·13	0·26	0·04	6·50	6·2	83·49	4·60	6·31	10·99	0·52	0·105
16 R 8	0—8 in.	A	3·01	7·53	2·50	0·134	18·9	6·5	73·59	5·68	9·14	14·32	0·30	0·140
	8 in.—2 ft.	B	2·80	4·02	0·39	0·055	7·1	5·7	76·46	6·72	8·48	15·20	0·71	0·077
	2 ft.—4 ft.	C	1·60	3·11	0·09	0·015	6·2	5·6	81·38	5·36	7·50	12·86	0·59	0·021
X14 Y23	0—5 in.	A	3·41	12·24	5·46	0·34	16·1	6·8	71·53	3·65	8·21	11·86	0·64	0·280
	5 in.—8 in.	B	2·16	5·77	1·83	0·14	13·1	6·4	77·06	4·59	9·69	14·28	0·51	0·112
	8 in.—2 ft. 6 in.	C	1·40	2·78	0·27	0·04	6·8	6·9	82·89	5·67	6·63	12·30	0·10	0·035
X25 Y19	0—1 ft.	A	3·77	11·44	4·76	0·25	19·04	6·2	69·15	5·23	8·84	14·07	0·69	0·322
	1 ft.—1 ft. 8 in.	B_1	2·82	4·03	0·72	0·08	9·00	5·8	76·87	5·57	9·09	14·6	1·00	0·049
	1 ft. 8 in.—3 ft. 11 in.	B_2 & C	2·68	3·12	0·25	0·05	5·00	6·4	78·07	5·47	8·50	13·97	1·23	0·070

TABLE VI

Analytical results of brown forest soils (mechanical determinations)

(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent	Exchange H m. e. (per cent)
X5 Y20	0—8 in. . .	4·53	35·82	31·25	21·75	0·18
	8 in.—1 ft. 7 in.	2·88	43·43	31·03	19·70	0·26
	1 ft. 7 in.—3 ft. 1 in.	15·98	52·30	18·30	11·85	0·35
X7 Y22	0—1 ft. . .	4·61	37·14	25·15	20·75	0·35
	1 ft.—2 ft. 6 in.	7·34	36·25	28·00	23·85	3·33
	2 ft. 6 in.—3 ft.	11·36	51·39	21·85	14·15	2·71
16 R 8	0—8 in. . .	4·89	26·48	37·10	27·65	7·25
	8 in.—2 ft. .	4·24	27·57	38·30	29·50	6·56
	2 ft.—4 ft. .	33·84	43·70	7·90	16·50	3·24
X14 Y 23	0—5 in. . .	15·52	30·11	26·25	16·40	..
	5 in.—8 in. .	24·83	36·55	15·85	16·40	0·044
	8 in.—2 ft. 6 in.	30·72	43·21	13·70	11·0	..
X25 Y19	0—1 ft. . .	1·05	22·48	39·10	23·10	..
	1 ft.—1 ft. 8 in.	0·82	28·60	42·30	23·35	..
	1 ft. 8 in.—3 ft. 11 in.	1·00	31·63	36·95	27·05	..

These soils possess characteristics which are essentially similar to those identified as 'Braunerde' of Ramann. Although varying only in texture, the majority of the soils so far studied at Chaubattia possess the characteristics of this group.

The zone of accumulation of organic debris or jungle litter, i.e. A_0-horizon is usually absent, which is due to absence of forest cover and intense surface erosion. The first surface layer of soil is, therefore, rich in humified matter and reaches a depth of about a foot. It is usual to find most of the plant roots crowding in this horizon, the structure of the soil aggregates is usually granular. This horizon is always extremely acid. The highest quantity of lime in loamy

or sandy loam profiles is associated with the surface organic layer. The contents of magnesia in this horizon are usually lower than that in the next horizon.

The pre-eminent character of the second horizon is its distinctly brownish colour. In most roadside cuttings one cannot mistake this layer extending in a tongue-like fashion into the third horizon. In loamy soil, therefore, this is the first zone of accumulation of sesquioxides, particularly iron, which is apparently the reason of the striking colour of this horizon. The soils of this horizon are more acid than those of the preceding horizon and have lower content of organic matter and lime. This horizon in most cases shows the highest amount of magnesia. The aggregates are some times granular, but more often are structureless. The position of profiles along the slopes determines the textural character of this horizon. In mild slopes it has a lighter texture than the one preceding it (viz. X5Y20); but at the bottom of slopes or pockets of hills this horizon shows a granular structure and heavier texture; but the brown colour of the horizon under all conditions is very apparent.

The third horizon shows different characteristics depending on the position of the profile along the slopes. On steep slopes of about 45° or more this horizon is usually yellow and sandy, turning slightly brown when wet. It is usual to find feeder roots invariably avoiding this horizon. The soil in this case is structureless and sandy.

In sesquioxides and lime this horizon is the poorest. On account of the richness of the parent rock in magnesia, the latter in the case of some profiles is found in higher quantity in this horizon, e.g. X7 Y22. In the case of those profiles which are situated along slopes of less than 45° this horizon shows a heavier texture, and is more brownish yellow in colour with sometimes dark bluish incrustations, e.g. X25 Y19. In the pockets of hills or at the bottom of slopes, owing probably to impeded subsoil drainage, this horizon shows rock-like consistency. The structural aggregates in the latter case are angular. The soil material synthetically is a mixture of infiltered clay and decomposing parent material. In relative chemical attributes this horizon is not very different from the usual C-horizons of the loamy grey brown profiles.

The pan formation in the case of brown soils takes place in the pockets of hills which are the only places where drainage takes place vertically. At other places it is usual to expect the subsoil-drainage flow parallel to the surface of the bed rock or surface soil. Along steep slopes translocation of material takes place parallel to the surface and this might be the reason why on steep slopes we do not meet with pan formation while this is invariably present at the bottom of slopes, or along slopes having about 20° inclination.

The above characteristics of the brown forest soils studied by us are not strictly analogous to those of the types described by Ramann [1928] to which the universal name 'Braunerde of Ramann' is given. The latter have normally a neutral or slightly alkaline reaction, and hence the humus bodies are not found under dispersed condition. Glinka [1928] considered these soils as a variety in the podsol zone formed on parent material rich in lime.

Tamm [1930] however has recognised two sub-types of brown soils in Southern Sweden and has divided them into climatic and acclimatic types. The former type of formation develops on parent material poor in lime, whereas the latter forms on calcareous material. Mitchell and Muir [1935] have adduced evidence showing that brown soils of England do not show the

characteristics usually associated with brown soils of Ramann. That the brown forest soils have been developed under podsolic conditions have been recognised by all the authors cited. Besides Ramann has recognised that 'In no other formations does the parent rock exercise such a great influence as in brown earths'. The brown soils studied by us therefore can be considered as a sub-type of brown forest soils formed from acid igneous rock having analogous development in Miami and Russell series. Baldwin [1928], has analysed some of these brown soils which appear to have the same general characteristics as our soils.

For elucidating more fully the pedogenic processes undergoing in these soils, it was considered desirable to analyse the clay fraction alone for SiO_2, Al_2O_3 and Fe_2O_3. The results for two typical profiles are given in Table VII.

Table VII

Analysis of clay fraction—brown forest soils

Profile	Depths	Horizon	SiO_2 (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
X5 Y20	0—8 in.	A	41·91	15·41	22·09	3·22	2·22
	8 in.—1 ft. 7 in.	B	44·12	15·41	18·94	3·95	2·60
	1 ft. 7 in.—3 ft. 1 in.	C	44·27	15·17	17·03	4·41	2·81
X7 Y22	0—1 ft.	A	44·40	11·58	25·02	3·01	2·34
	1 ft.—2 ft. 6 in.	B	42·28	12·78	26·82	2·67	2·11
	2 ft. 6 in.—3 ft. 10 in.	C	43·06	11·98	25·72	2·84	2·29

The data given in Table VII clearly indicate that there is no marked eluviation of sesquioxides or silica in these profiles—a characteristic which is typical of continental brown forest soils. Further the silica-alumina ratio as well as the silica-sesquioxide ratio show that within limits the consistency of the clay complex is the same throughout the profile.

Podsols

Twelve profiles showing the characteristics of podsolic development have been analysed in detail and visual characters have been studied for 50 more

profiles. The visual characters of the horizons constituting each of six typical profiles are given below :

Visual characters of podsolic profiles

Profile Nos.	Horizon	Depths	Characters
X8 Y25	A_1	0—7 in. . .	Dark grey ; clayey ; finely granular ; organic soil containing roots ; darkens in colour when wet.
	A_2	7 in.—2 ft. .	Yellowish brown ; sandy loam ; stony soil. More brown when wet.
	B+C	2 ft.—3 ft. 2 in.	Brownish clayey ; slightly granular soil. More brown when wet. The clay particles have dark bean-shaped iron concretions.
X7 Y20	A_1	0—1 ft. 3 in. .	Dark grey ; coarsely granular ; clayey soil. More dark when wet.
	A_2	1 ft. 3 in.—2 ft. 4 in.	Sandy ; micaceous ; stoney ; yellowish horizon containing some undecomposed rock. More brown when wet.
	B+C	2 ft. 4 in.—3 ft. 10 in.	Brownish ; clayey ; micaceous ; stony soil. More brown when wet.
9 S I	A	0—1 ft. .	Greyish brown clayey. More brown when wet. Granular.
	A_1	1 ft.—2 ft. 8 in.	Clayey ; brownish soil. More brown when wet.
	A_2	2 ft. 8 in.—3 ft. 6 in.	Reddish brown. Sandy micaceous soil. Deep brown colour when wet.
	B + C	3 ft. 6 in.—4 ft. 6 in.	Clayey ; greyish brown soil. More brown when wet.
8 R 5	A	0—1 ft. 2 in.	Dark grey ; granular ; loam with some undecomposed organic matter. More dark when wet.
	A_1	1 ft. 2 in.—2 ft. 6 in.	Brownish grey ; heavy loam. Slightly dark when wet.
	A_2	2 ft. 6 in.—3 ft. 4 in.	Brownish yellow ; loam ; lighter than above. More yellow when wet.
	B	3 ft. 4 in.—5 ft.	Hard, lumpy, brown pan with white cementation and dark incrustations. More brown when wet.

Visual characters of podsolic profiles—contd.

Profile Nos.	Horizon	Depths	Characters
Mixed No. 4 (Plate XLV, fig. 2)	A	0—2 in. . .	Granular, with brown markings, loamy; dark grey when wet.
	A_2	2 in.—8 in. .	Soil same as above mixed with some stones and single-grain sand.
	B_1	8 in.—1 ft. 5 in.	Whitish brown with sandy cementation; dark and brown incrustations loam. More brown when wet.
	B_2	1 ft. 5 in. and below	Dark grey, angular, clayey hard soil with black incrustations. More dark in colour when wet.
9R 4]	A_1	0—1 ft. . .	Greyish brown; granular; organic loam. More dark when wet.
	A_2	1 ft.—4 ft. 10 in.	Granular; greyish brown; slightly micaceous; loam. Slightly darker when wet.
	B_1	4 ft. 10 in.—6 ft. 10 in.	Dark grey; heavy loam; more dark when wet.
	B_2	6 ft. 10 in.—7 ft. 10 in.	Brownish grey; heavy loam; more dark when wet.
	B_3+C	7 ft. 10 in. and below	Reddish brown; hard clay pan, with whitish cementations and dark incrustations. More red when wet.

The complete chemical analysis and mechanical compositions of the above profiles are given in Tables VIII and IX.

This type of development is met with under mild slope gradients, and in the pockets of hills and ridges, and in the shady places of the orchard. The surface erosion due to the particular topography is not as intense as in grey brown forest soils. Although there is considerable accumulation of organic matter from the decomposing leaves and grasses, the surface soil does not tend to be peaty. The horizon differentiation is very clear in all cases.

The first horizon contains a soil rich in humus in a dispersed condition which gives the soil a granular structure. As expected, the maximum crowding of the plant roots is found in this horizon. The colour of the soil shades from dark grey to brownish grey. The soil is mostly clayey which is not much indurated owing to the presence of humus. Depending upon the position of the profile along slopes this horizon sometimes shows a sub-horizon (e.g. 9SI, and 8R5) and the total depth of 3 ft. is recorded for such horizons. Sub-horizons indicated above show the characteristics of the B-horizon of the brown forest soils, namely alluvial additions of colloidal matter and sesquioxides from the preceding horizons.

TABLE VIII

Chemical analysis of podsolic profiles

Name of profile	Depth	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	pH	Insoluble matter (in strong HCl)	Fe_2O_3	Al_2O_3	R_2O_3	MgO	CaO
		Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
X8 Y25 A_1	0—7 in.	3·41	9·86	3·82	0·23	16·60	6·8	72·02	4·56	8·42	12·98	0·40	0·413
X8 Y25 A_2	7 in.—2 ft.	1·43	2·54	0·34	0·05	6·80	6·3	82·88	3·82	7·70	11·52	0·12	0·126
X8 Y25 B+C	2 ft.—3 ft. 2 in.	2·19	4·16	0·30	0·06	5·00	5·6	75·86	5·62	9·66	15·28	0·31	0·105
X7 Y20 A_1	0—1 ft. 3 in.	2·99	8·96	3·59	0·25	14·36	7·0	73·20	3·47	9·67	13·14	0·53	0·462
X7 Y20 A_2	1 ft. 3 in.—2 ft. 4 in.	1·23	2·70	0·36	0·08	4·45	6·8	85·10	3·19	6·39	9·58	0·34	0·147
X7 Y20 B+C	2 ft. 4 in.—3 ft. 10 in.	1·64	2·49	0·08	0·03	2·60	5·6	81·46	4·11	8·25	12·36	0·50	0·070
SI A	0—1 ft.	2·92	5·75	1·37	0·126	10·96	6·3	76·10	6·40	6·85	13·25	1·014	0·161
SI A_1	1 ft.—2 ft. 8 in.	3·50	4·05	0·32	0·050	6·35	5·6	76·31	6·80	7·31	14·11	0·988	0·084
SI A_2	2 ft. 8 in.—3 ft. 6 in.	1·52	2·68	0·070	0·018	3·86	5·5	86·04	3·76	5·10	8·86	0·336	0·021
SI B+C	3 ft. 6 in.—4 ft. 6 in.	2·78	3·55	0·212	0·036	5·73	6·0	79·73	6·16	5·28	11·44	0·823	0·049
8R5 A	0—1 ft. [illegible] in.	3·60	8·48	2·88	0·171	16·9	6·0	72·68	5·28	7·93	13·21	0·65	0·140
8R5 A_1	1 ft. 2 in.—2 ft. 6 in.	3·42	5·41	1·21	0·098	12·4	5·7	73·51	6·08	9·91	15·99	0·73	0·121
8R5 A_2	2 ft. 6 in.—3 ft. 4 in.	2·56	4·19	0·37	0·050	7·2	5·6	77·2	5·44	8·57	14·01	0·239	0·035
8R5 B+C	3 ft. 4 in.—5 ft. 6 in.	3·30	4·25	0·30	0·060	5·0	5·5	76·17	6·40	9·15	15·55	0·91	0·177
Mixed No. 4 A	0—2 in.	3·86	13·89	6·08	0·440	13·81	5·9	68·08	4·63	8·76	13·39	0·57	0·161
Mixed No. 4 A_1	2 in.—8 in.	2·86	7·96	2·730	0·252	10·81	5·7	75·56	4·23	8·53	12·76	0·66	0·077
Mixed No. 4 B_1	8 in.—1 ft. 5 in.	3·04	3·53	0·470	0·066	7·12	5·9	78·15	5·83	7·88	13·71	1·01	0·172
Mixed No. 4 B_2	1 ft. 5 in. and below	3·86	4·43	0·86	0·077	11·20	6·2	75·00	6·21	8·75	14·96	0·86	0·462
9R4 A_1	0—1 ft.	3·87	10·82	3·59	0·181	19·8	6·0	71·0	5·36	8·51	13·87	0·236	0·196
9R4 A_2	1 ft.—4 ft. 10 in.	3·55	5·12	0·94	0·073	12·9	5·7	75·4	5·84	8·34	14·18	0·449	0·077
9R4 B_1	4 ft. 10 in.—6 ft. 10 in.	4·19	7·17	1·79	0·083	21·6	5·6	72·7	5·60	9·77	15·37	0·328	0·056
9R4 B_2	6 ft. 10 in.—7 ft. 10 in.	3·39	4·16	0·54	0·055	9·8	5·5	76·7	5·76	8·35	14·11	0·300	0·049
9R4 B_2+C	7 ft. 10 in. and below	4·86	4·06	0·12	0·035	3·4	5·8	73·3	6·64	9·70	16·34	0·233	0·084

TABLE IX

Mechanical analysis of podsolic profiles
(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand	Fine sand	Silt	Clay	Exchange H+ m.e.
		Per cent	Per cent	Per cent	Per cent	Per cent
X8 Y25	0—7 in.	6·42	32·13	33·05	24·20	0·088
	7 in.—2 ft.	12·42	40·13	25·20	18·60	1·75
	2 ft.—3 ft. 2 in.	8·46	32·70	25·00	30·90	2·27
X7 Y20	0—1 ft. 3 in.	6·14	31·80	30·45	23·20	..
	1 ft. 3 in.—2 ft. 4 in.	13·55	47·93	21·05	15·50	..
	2 ft. 4 in.—3 ft. 10 in.	..	39·48	26·50	22·45	0·18
9SI	0—1 ft.	4·12	23·68	40·22	25·88	0·088
	1 ft.—2 ft. 8 in.	1·83	23·50	39·13	31·55	3·98
	2 ft. 8 in.—3 ft. 6 in.	19·28	49·51	14·30	18·40	2·98
	3 ft. 6 in.—4 ft. 6 in.	8·18	29·31	32·82	28·98	0·33
8R5	0—1 ft. 2 in.	3·38	24·66	39·80	29·35	2·62
	1 ft. 2 in.—2 ft. 6 in.	3·70	21·33	40·50	34·75	2·45
	2 ft. 6 in.—3 ft. 4 in.	3·98	24·9	43·30	28·50	2·50
	3 ft. 4 in.—5 ft.	0·57	21·81	43·75	32·85	1·66
Mixed No. 4	0—2 in.	2·83	22·09	30·75	26·40	Trace
	2 in.—8 in.	5·94	29·53	33·15	22·60	0·525
	8 in.—1 ft. 5 in.	2·28	28·48	40·40	24·15	Trace
	1 ft. 5 in. and below.	0·31	20·98	40·75	30·75	Trace
9R4	0—1 ft.	3·03	21·9	40·8	27·7	0·26
	1 ft.—4 ft. 10 in.	5·34	24·7	39·2	28·6	4·2
	4 ft. 10 in.—6 ft. 10 in.	3·18	18·2	40·2	33·4	4·73
	6 ft. 10 in.—7 ft. 10 in.	5·66	21·5	42·5	27·9	3·68
	7 ft. 10 in. and below	1·79	21·1	40·6	34·2	1·75

This observation is certainly peculiar. In no podsolic development a sub-horizon of the nature enumerated here has been found associated with the A_1-horizon, as the preceding horizon is neither peaty nor possesses any decomposed organic accumulation.

Underlying the A_1-horizon is found the A_2-horizon which in the cases of loamy profiles is mostly sandy loan (e.g. X8 Y25, X7 Y20) and is the zone of maximum eluviation.

In the cases of clayey profiles this horizon shades from yellow to brown with sandy grains showing more or less a bleached appearance cemented round the structural soil mass. In all these profiles physical eluviation particularly of clay is very apparent, and among the soil ingredients the content of fine sand in this horizon is maximum. Amongst the chemical attributes, it is interesting to note that in this horizon the largest amount of SiO_2 (insoluble matter in strong HCl) is associated with the least amount of sesquioxides, and unlike grey brown forest soils, we find lowest amount of magnesia in this horizon. Excepting a few profiles (e.g. X8 Y25 and X7 Y20) we also find considerable eluviation of lime from this horizon. In organic carbon and nitrogen, for the majority of the profiles, this horizon is found to be strikingly impoverished. Thus in short the A_2-horizon is considerably eluviated of finer matter, sesquioxides and bases.

Underlying the A_2-horizon, the horizon of maximum illuviation, namely 'B' is situated. This horizon in most cases cannot be differentiated into B_1 and B_2. In loamy profiles it is, in the majority of cases, brown and clayey, and when moist some sort of a granular structure is apparent. There are imbedded in the soil mass bean-shaped, sometimes needle-like, black iron concretions.

In clayey profiles this horizon shows rock-like consistency by forming a hard clay pan. Two types of such pans are encountered under our conditions. The first one of importance possesses a brownish colour and soil aggregates are arranged in prismatic form (e.g. 4th horizon of 8R5). The second type shows a dark grey colour, with angular soil aggregates (e.g. 4th horizon of mixed No. 4). These two types of pans are essentially different from each other as will be seen from Table IX*a*.

It is interesting to note that in some profiles these two types of pans are found to occur together (e.g. 9R4) where the humus pan precedes the iron one. In all the above cases, however, a white sandy cementation is found round the soil aggregates which appear to be, as will be clear from the table on page 1012, eluvial material of the A_2-horizon mechanically carried downwards.

Chemical analysis of the clay pans (Table IX*a*) shows that illuviation of sesquioxides and bases takes place in this horizon.

The C-horizon is generally found to be constituted of decomposing rock mixed with infiltered clay and there is no clear demarcation of boundaries between the B and C horizons, which appear to be blended together. The third horizon of X7 Y20 seems to contain decomposing rock debris mixed with some finer material washed down from the preceding horizons. In clayey profiles, this composition is found towards the bottom of the B-horizon.

TABLE IX*a*

Analytical results of some clay pans

Name of profile	Depth	Description	Clay	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	SiO_2	Fe_2O_3	Al_2O_3	*p*H
			Per cent	Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	
X14 Y25	4 ft. 1 in.—4 ft. 10 in.	Iron pan	25·25	2·83	3·68	0·51	0·06	8·5	78·36	3·23	10·69	5·1
X15 Y15	3 ft. 5 in. and below	Iron pan	26·15	3·02	2·56	0·34	0·06	5·21	76·95	3·86	10·13	...
3R5	3 ft. 4 in.—5 ft.	Iron pan	32·85	3·30	4·25	0·30	0·060	5·0	76·17	6·40	9·15	4·1
X15 Y28	1 ft. 6 in.—2 ft.	Humus pan	23·10	2·91	5·30	1·48	0·08	18·5	78·48	4·45	8·47	3·8
9L4	4 ft. 10 in.—6 ft. 10 in.	Humus pan	33·4	4·19	7·17	1·79	0·083	21·6	72·7	5·60	9·77	3·9

Chemical analysis of cement soil mass of B-horizon

Components	SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO
Cement . .	86·53	1·84	5·21	7·05	0·37	0·91
Hard clay .	..	..	..	..	..	..
(Mean of four) .	77·06	9·22	5·27	14·49	0·20	1·05

Podsolic formations have been studied in greater detail than any other formations owing to their occurrence in Northern Europe and Russia by such eminent authorities in soil science as Ramann, Glinka, Dokuchaev, etc. The peculiar features of this development is to no small extent responsible for the development of the modern conception of soil science. Various hypotheses about the causes responsible for the development of the peculiarities of podsols have been advocated from time to time. Ramann [1928] and Dokuchaev [1879] advanced the theory that organic acids are responsible for the formation of podsols. The bleached appearance of the A_2-horizon had been attributed to the light coloured crenic acid by Tumin [1911]. Glinka [1928] was of the opinion that colloidal matters of the A-horizon are washed down under the protective action of humus. Thus the horizon so impoverished of finer matter assumes a whitish colouration owing to the presence of qurtz sand. Robinson [1932] considered that the dominant factors in the development of the podsols were the prevalence of intense bleaching owing to excessive humid condition and parent material with poor base resource. Gedroiz's [1929] essentially physico-chemical views on the formation of the A_2-horizon are the decomposition of the unsaturated aluminium silicates into silica and sesquioxides after the colloidally dispersed humic acids which have been carried downwards. The recent investigation of Mattson [1933] suggests that the processes of podsolisation are related to the condition of acid hydrolysis prevalent in the podsolic zones. A-horizon under these conditions becomes saturated with hydrogen ions and a partial decomposition of the aluminium silicate complex necessarily takes place. Owing to a periodic shift of the pH of the environment the sesquioxides move downwards leaving behind silica. These deposit a short distance below owing primarily to pH of the B-horizon which controls the electrostatic forces. Ramesov [1937] has criticised this view of acid weathering. On account of the forest condition the dispersion is attributed by him to be brought about by ammonia formed from the decomposing organic debris. The absolute composition of the concretions found in the B-horizon has been studied by Morozov [1938] and Winter [1938] who find these to be richer in sesquioxides and manganese but poor in silica.

Aaltonen [1938] has found that in young soils the organic colloids, particularly of iron, are precipitated at comparatively lower depths than in old soils. The former are more acid and poorer in base-mineral indices. From this it appears that there are two distinct phases in the podsolic formations. At first the soils deepen with age and after a certain time the process is reversed ; B-horizon rises to the surface accompanied by the gradual decrease of soil acidity. When the soils of Chaubattia are viewed from this angle, the peculiar observation as the lack of a humus pan before iron one is fully understood, and the extreme acidity may, therefore, be attributed partly to the age of the profiles.

As in the case of the brown forest soils, clay fraction of the two of profiles discussed above was also analysed for SiO_2, Al_2O_3 and Fe_2O_3. The data are given in Table X.

TABLE X

Analysis of clay fraction—podsolic profiles

Profile	Depth	Horizon	SiO_2 Per cent	Fe_2O_3 Per cent	Al_2O_3 Per cent	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Mixed No. 4	0—2 in.	A_1	47·40	8·38	19·32	4·16	3·24	3·63
	2 in.—8 in.	A_2	47·02	8·78	19·02	4·19	3·24	3·39
	8 in.—1 ft. 5 in.	B_1	48·34	11·58	14·52	5·64	3·74	1·96
	1 ft. 5 in. and below	B_2	47·82	11·98	14·52	5·58	3·66	1·90
9S1	0—1 ft.	A	44·20	11·58	27·22	2·75	2·16	3·66
	1 ft.—2 ft. 8 in.	A	45·06	12·78	25·22	3·02	2·29	3·09
	2 ft. 8 in.—3 ft. 6 in.	A_2	45·94	15·13	18·17	4·29	2·80	1·88
	3 ft. 6 in.—4 ft. 6 in.	B+C	45·93	12·38	17·22	4·52	3·10	2·18

It appears from the figures given in Table X that although the clay-complex judged by the SiO_2/R_2O_3 ratios remains constant at all depths of the profiles, a marked eluviation in regard to Fe_2O_3 is obvious. This is also borne out by the diminution of the Al_2O_3/Fe_2O_3 ratio in the B-horizons, showing that, according to expectation, there has been a greater mobility in respect of Fe_2O_3 than Al_2O_3. The results as a whole, however, indicate that in the formation of soils in these parts, physical weathering plays a far more important role than chemical weathering. The somewhat erratic nature of the values given by the last horizon of 9S1 profile is attributed to the fact that it is a composite of B and C-horizons.

WIESENBODEN FORMATIONS

Four profiles under this group were analysed in detail and visual characters have been studied for fourteen more profiles. The visual characteristics of the horizons constituting each of three typical profiles are briefly given below :—

Visual characteristics of Wiesenboden profiles

Profile No.	Horizon	Depth	Characteristics
9R1	A	0—6 in.	Organic ; loamy ; dark grey soil. More dark when wet. Containing undecomposed organic matter.
	B+C	6 in.—1 ft.	Sandy loam ; slightly organic ; grey soil with undecomposed mica bits. Darkens when wet.
A9 R4	A	0—6 in.	Dark grey ; granular with brown spots ; sandy loam ; micaceous. More dark when wet.
	A_1	6 in.—1 ft. 2 in.	Granular ; dark grey ; sandy loam, darker than above, with a bluish tinge and dirty brown spots round mica pieces. This horizon contains mica stones.
	B+C	1 ft. 2 in.—1 ft. 6 in.	Yellowish ; micaceous ; sandy soil ; brownish yellow when wet.
26 Y19	A_1	0—9 in.	Granular ; brownish grey ; micaceous loam with few stones. More dark when wet.
	A_2	9 in.—1 ft. 3 in.	Greyish brown ; stony loam ; micaceous ; granular. Darkens when wet.
	B_1	1 ft 3 in.—2 ft.	Angular ; grey lumpy ; heavy loam. Micaceous with mica stone imbedded in soil mass and dark incrustations ; dark grey when wet.
	B_2+C	2 ft.—3 ft.	Greenish blue ; loam ; micaceous with some mica stones ; rather heavy ; reddish brown spots at places. Dark blue when wet.

The detailed analytical figures of the above profiles are given in Tables XI and XII.

TABLE XI

Results of chemical analysis of Wiesenboden formations

Name of profile	Depth	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	pH	Insoluble matter	Fe_2O_3	Al_2O_3	R_2O_3	MgO	CaO
		Per cent	Per cent	Per cent	Per cent			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
9RI A	0—6 in.	4·98	15·29	8·23	0.515	16·0	6·4	66·63	4·80	5·17	9·97	0·47	0·658
B+C	6 in.—1 ft.	2·08	4·79	1·68	0·134	12·5	6·6	81·61	4·56	5·63	10·25	0·31	0·175
A9 R4 A	0—6 in.	2·73	8·10	3·03	0·255	11·88	6·8	78·68	3·37	6·15	9·52	0·35	0·245
A_1	6 in.—1 ft. 2 in.	2·33	5·55	2·03	0·164	12·38	6·4	77·11	3·35	5·68	9·03	0·44	0·175
B+C	1 ft. 2 in.—1 ft. 6 in.	1·55	3·41	0·66	0·070	9·43	6·3	84·01	4·75	8·00	12·75	0·52	0·084
A62 Y19 A_1	0—9 in.	3·44	8·80	3·55	0·225	15·78	6·7	74·61	4·51	7·16	11·67	0·72	0·2100
A_2	9 in.—1 ft. 3 in.	2·66	5·23	1·60	0·118	13·56	6·8	77·99	4·79	8·04	12·83	0·57	0·147
B_1	1 ft. 3 in.—2 ft.	2·79	5·25	1·56	0·111	14·06	6·6	74·68	4·95	8·65	13·60	0·43	0·238
B_2+C	2 ft.—3 ft.	2·40	5·37	2·03	0·074	27·44	6·5	81·05	4·01	7·08	11·09	0·62	0·330

TABLE XII

Mechanical analysis of Wiesenboden formations

(*Analysis of 2 mm. sample*)

Name of profile	Depth	Coarse sand	Fine sand	Slit	Clay	Ex-change H m. e.
		Per cent	Per cent	Per cent	Per cent	Per cent
9RI	0—6 in.	8·27	23·09	32·25	23·25	0·088
	6 in.—1 ft.	26·57	32·17	23·80	15·80	0·088
A9 R4	0—6 in.	13·40	45·69	19·65	12·25	
	6 in.—1 ft. 2 in.	24·81	38·38	19·30	12·25	
	1 ft. 2 in.—1 ft. 6 in.	22·98	42·72	23·50	10·05	
A62 Y19	0—9 in.	14·94	36·33	23·80	14·90	
	9 in.—1 ft. 3 in.	15·68	37·02	24·50	17·95	
	1 ft. 3 in.—2 ft.	9·50	30·23	35·15	20·55	
	2 ft.—3 ft.	12·10	33·93	33·35	16·25	

This type of profile development is not by any means very common in these parts and is usually met with near *nullas* or water streams and cool and shady low-lying places of the orchard. Owing to very high ground water-level, the soil remains always moist, and during winter a thick matting of frost covers the soil surface during the entire season. The organic matter due to water-logged condition is not completely decomposed to humus, and it is usual to find a horizon of organic debris of about an inch thick on the surface soil in a semi-decomposed state. The surface horizon is, therefore, very dark in colour, and coarsely granular. It is found that *in situ* this dark colour deepens downwards. In some profiles, e.g. A9 R4 it has been found that the organic horizon occurs as two sub-horizons with distinct marks of demarcation and it is the lower horizon which appears to be more organic than the surface. In reality however the surface soil on analysis gives higher carbon content owing presumably to undecomposed organic matter. The carbon-nitrogen ratio of this layer on the other hand is found to be higher than that of the surface soil. But in most cases these profiles are marked by their shallowness and waterlogged conditions. The second horizon is often found to be a decomposing rock, sometimes brown but more often slightly bluish and invariably very light, stony and structureless. Considerable

amount of organic matter is sometimes found in this horizon, but the difference in the organic matter content between this horizon and the surface layer is very marked. From the description of the profiles as given above it is clear that this type of profile development is essentially hydrogenic in nature. As a result of intensive soil survey carried out at Chaubattia it is obvious that profiles of this nature are by no means common under the existing conditions of the locality.

The formation of soils falling under this group is in fact due to certain inter-zonal processes resulting in an aggregate profile similar to that of Wiesenboden. The chief pre-disposing causes leading to the evolution of soils of this type at Chaubattia are waterlogging of the sub-soil, low temperature, and presence of vegetations such as grasses and undergrowths like *Rhubus*, *Renunculus*, *Ophiopogon*, *Pteris*, etc.

Another striking point which emerges out of these observations is that, although in general this group can be classified as Wiesenboden, the profile development shows two distinct phases, namely brown forest and podsolic characteristics. Of the profiles described above A62 Y19 shows definite podsolic tendencies, whereas the characteristics of the grey brown forest soils are indicated in the rest.

These soils are better known as 'meadow soils' after Robinson [1932] who describes these as 'soils whose profile characteristics are dominated by the occurrence of a high water-table or an impervious layer impeding percolation'. Kellog [1936] thinks that, when properly drained by artificial means, Wiesenboden provides some of the most fertile land in the world for crops. Its occurrence in other soil groups has also been indicated by him.

The question of gley formation in the podsol zone has been discussed by Frosterus [1914] and the role that the dissolved oxygen plays in soil water in gley formations has been investigated in detail by Tamm [1925]. This has thrown considerable light on the peculiar features of hydrogenic soils.

General discussion

The detailed study of soils developed under the climatic conditions of Chaubattia in Kumaun clearly shows that local conditions as a whole favour the development of soils similar to, but not identical with, the brown soils of the international groups. The processes giving rise to this type of development seem to be similar to those causing the development of podsols. The surface shows a well-developed organic horizon which does not tend to be peaty and the structural aggregates are finely granular. The second horizon possesses a brownish to reddish brown colour. This may be attributed to the dehydration and oxidation of sesquioxide sols eluviated under the protective action of acid humus from the upper horizon, since according to Mattson [1933] high acidity cannot favour the mobilization of silica although the sesquioxide soils may be gradually washed down under such conditions. The presence of humus in excess sometimes masks this brown colour and causes the development of a greyish brown colouration. Along with the sesquioxides, lime and magnesia are also washed down to the second horizon. This brownish horizon, therefore, corresponds with the usual B-horizon of the international group of brown forest soil. The third horizon, however, shows

characteristic differences according to the topography of profile development. Along steep slopes this horizon is very light, loose, stony and structureless with a pre-eminently yellow colour, whereas at the flat end of hill-slopes this horizon consists of a brownish hard pan ; the latter is due presumably to hydrated ferric oxide, as on ignition the soil assumes a reddish brown colour. It is interesting to observe that plant-roots generally avoid the third horizon along steep slopes. Even grasses refuse to grow on this type of soil. This might be attributed either to the presence of some toxic ingredient in this horizon or absolute poverty in food material and moisture.

Chemical analysis does not, however, reveal any unusual deficiency in plant-nutrients and under field conditions sufficient moisture is found to be present. Thus it may be concluded that the aversion of the plant-roots to traverse this horizon is due to some toxic ingredient.

The formation of a brown hard pan in the third horizon under the topographical conditions stated above has sometimes been interpreted as characteristics of podsolic developments [Ramann, 1928]. Our studies, however, definitely show that brown forest soils as distinct from podsols can form hard pans under certain topographical conditions. Along steep slopes where brown soil formations take place, the subsoil drainage is roughly parallel to the surface and rock-bed. This is one of the reasons underlying the hydration of sesquioxides of the third horizon. The sesquioxide sol under such drainage conditions can move only along the B-horizon down the slopes ; but at places where this movement can take place vertically, as is the case at the flat end of the hills, the sol during dry period may be dehydrated and in course of time, as stated above, result in pan formation tending to the juxtaposition of the B and C-horizons.

The natural result of a hard pan in the sub-soil sooner or later affects the surface soil. With high rainfall and the blocking up of sub-soil drainage at the pan, sheet erosion might occur, with the result that a considerable quantity of organic matter is washed away from the surface soil. This appears to account for the poor organic status of the surface soil in most of the clay profiles.

Second in importance to the brown forest soils, podsolic formations are encountered under certain local conditions as has been stated already. The topographical position of these profiles is such that the soils experience alternate wetting and drying, a cool humid climate due to shady surroundings and above all sufficient organic matter accumulation due to annual leaf-fall in the spring. Under these conditions it is natural that podsols would develop. Most of the podsolic profiles studied by us are clayey to loamy, and two types of hard pans have been met with. The conditions favouring the formation of such pans have not been determined, excepting that humus pan has a lower pH than the iron pan. The study of these pans in the hills becomes more difficult when one finds these to be superimposed on the C-horizon with no well-defined line of separation.

Data have been presented about soils showing red loam and gleization tendencies. At any rate these are not typical formations of the station. The suggestion is clear, however, that if through human intervention or otherwise the specific conditions leading to their development be produced anywhere on the orchard, the soil in that locality would tend to assume the characteristics of red loam or Wiesenboden types.

It should, however, be clearly understood that most of the soils on this orchard are as yet somewhat immature as revealed by their stony nature. Although we have reported on four major types of the formation usually met with in this locality, the detailed survey has shown various intermediate developments which cannot be regarded as true pedogenic types. For instance, in some cases, it has been found that brownish grey organic surface soil is superimposed on a yellowish brown horizon which for true brown forest soils usually constitutes the C-horizon. But when this surface horizon is more closely examined a brownish layer of about one-tenth of an inch or so in thickness is usually found. This type of profile is very shallow and is found along slope of 60° or more.

The analytical data for the clay fraction of brown forest soils occurring on this orchard do not reveal any eluviation of the bases ; but in the case of podsols, on the other hand, considerable eluviation of Fe_2O_3 is observed to have taken place. The trend of the changes in the silica-sesquioxide ratios shows that physical weathering plays a more important part than chemical weathering in the formation of soils in these hills.

Summary

The pedogenic soil-forming processes under the climatic and topographical conditions of Chaubattia tend to produce four different soil types as given below :

Red loams

Soils corresponding to the temperate red-loams are found in dry places where the organic matter is rapidly mineralised owing to subsoil drainage conditions. Only a small number of profiles is found to possess these characteristics.

Brown forest soils

This formation is very general under the climatic conditions at Chaubattia and most of the soils of the locality belong to this type. The pre-eminent nature of the profiles of this type is brown colouration of the B-horizon and moderate organic status of the surface soil.

Podsols

The third formation which is met with under humid conditions shows podsolic tendencies although extreme cases of podsolization are not very evident.

Wiesenboden or meadow soils

The fourth type of development is analogous with the hydrogenic Wiesenboden formation and is usually found near *nullas* and in cool, shady and perpetually moist places.

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THE RELATION OF THE SIZE OF FRUIT TO THE LOSS IN WEIGHT IN STORAGE

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THE processes of respiration and transpiration continuously go on in fruit during storage, with the result that the fruit gradually loses in weight. The rate of loss depends on the temperature and the relative humidity in the storage chambers and also on the nature of the fruit. Wardlaw [1933] in his experiments on the storage behaviour of limes observed that the loss in weight was largely a function of size and that such loss was directly related to the area of fruit exposed. Leonard [1936] found that, in the case of grape fruit, the percentage loss in weight was less in fruits of bigger size. Wardlaw and Leonard [1936] showed the importance of size involving surface-bulk relationship in considering the rate of loss in weight during storage. Cheema and others [1939] found that, in the case of mangoes, the percentage loss in weight of small fruit was higher than that of big fruit at 68°F., but there was no difference at 48°F. Cheema and Karmarkar [1939] observed that in Malta oranges the size of fruit was very important. Fruit of big size remained firm, while fruit of small size shrivelled. During the course of the experiments conducted in this cold storage plant it has been found that the size of fruit influenced the rate of loss in weight in storage. The data obtained with different fruits are given in this paper.

Experimental procedure

Big and small size fruit of an apparently equal stage of maturity was selected for the experiments. The selection of the two sizes was made according to the weight of fruit as the specific gravity did not vary appreciably with the size. Ten fruits of each size (weighing within a selected range) were used. The fruits were individually weighed and kept in partitioned trays. One fruit was kept in each division and the partitions were given serial numbers so that in case a fruit rotted, it could be removed without disturbing the experiment. The fruits were kept in chambers maintained at different temperatures with the relative humidity between 80 and 90 per cent. The fruits were weighed at regular intervals and the rate of loss in weight was determined. The percentage loss in weight was calculated on fresh-weight basis. The ratio of percentage loss in weight of small fruit to the percentage loss in weight of big fruit was also obtained. Further, the thickness of skin, the percentage of pulp and the rate of respiration of fruits of the two sizes were determined. The data are given in Tables I-XI. The number within brackets just below the range of weights indicates the average weight of a fruit in grammes. For brevity the ratio of the percentages is shown as small/big or as big/small.

Discussion

The loss in weight in storage of fruits is due to the transpiration of water from the tissues and the decrease in solids during respiratory processes. A little loss may also be due to the evaporation of other volatile substances given off by the fruits. Wardlaw [1933], Leonard [1936] and Wardlaw and Leonard [1936] have noticed that the rate of percentage loss in weight in storage of fruits is related to the size of fruit and is greater in fruits of smaller size. The greater loss in weight of small fruit may be due to the larger surface exposed per unit volume resulting in a higher rate of transpiration. The data obtained in these experiments (Tables I—VIII) showed that the percentage loss in weight of small fruit was always greater than that of big fruit, except in the case of grape fruit at 68°F. The ratio of the percentage loss in weight of small fruit to the percentage loss in weight of big fruit remained practically constant during the storage period. The value of the ratio, however, was found to vary with the temperature of storage. In limes (Table V) the small/big ratio at 45°F. agreed well with the ratio for surface (big and small fruits) which was 1·24 when calculated by assuming limes to be of a perfect spherical shape. Resorting to the above method of calculating the surface ratio, the small/big ratio approximated the surface ratio which was 1·14 in the case of Mosambi and Malta oranges at the different temperatures. The calculated surface ratio in the case of the Nagpur orange was 1·15 and was equal to the small/big ratio at 52°F. only (Table VIII).

The high values of small/big ratio obtained in the case of chikoos (Table II), bananas (Table III) and limes (Table V) at 68°F. and the Nagpur orange (Table VIII) at 40° and 45°F. could not be accounted for by the surface-bulk relationship alone. The difference in the small/big ratios obtained for the same type of fruit at different temperatures of storage suggested that there were other factors which influenced the ratio.

Table I

Apples (variety, Hawthorn Greening)

Number of days of storage	Percentage loss in weight at 68°F.		
	Big 130-140 gm. (134)	Small 90-96 gm. (92)	$\frac{\text{Small}}{\text{Big}}$
8 . . .	1·51	1·67	1·11
16 . . .	2·67	2·85	1·07
24 . . .	3·80	4·08	1·07
32 . . .	4·85	5·24	1·08

TABLE II

Chikoo (Achras sapota, *globular type*)

Number of days of storage	Percentage loss in weight					
	52°F.			68°F.		
	Big 90-105 gm. (98)	Small 65-70 gm. (67)	Small/Big	Big 90-100 gm. (94)	Small 60-70 gm. (64)	Small/Big
3 . . .	..	..	..	3·13	4·30	1·37
5 . . .	3·22	3·92	1·22	..	..	..
6 . . .	..	..	..	5·98	8·14	1·37
9 . . .	..	..	..	9·06	11·45 (turned soft)	1·26
10 . . .	6·17	7·41	1·20	..	..	..
15 . . .	9·44	11·30	1·20	..	..	..
20 . . .	11·48	13·67	1·19	..	..	..

TABLE III

Banana (variety, Walha)

Number of days of storage	Percentage loss in weight					
	52°F.			68°F.		
	Big 105-120 gm. (113)	Small 65-80 gm. (69)	Small/Big	Big 105-120 gm. (112)	Small 60-75 gm. (67)	Small/Big
4 . . .	3·04	3·32	1·09	3·15	4·74	1·51
9 . . .	5·95	7·19	1·21	6·27	9·77	1·56
13 . . .	8·04	9·81	1·22	9·15	13·95	1·52
17 . . .	9·97	12·25	1·23	11·63	19·34	1·66
21 . . .	11·88	14·59	1·23	..	..	..

TABLE IV

Grape fruit (variety, Marsh's Seedless)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big 510-530 gm. (518)	Small 300-330 gm. (314)	Small/Big	Big 540-560 gm. (548)	Small 300-330 gm. (315)	Small/Big
8 . . .	1·37	2·03	1·48	3·10	2·89	0·93
16 . . .	2·94	3·46	1·18	5·63	5·43	0·96
24 . . .	4·58	4·82	1·05	7·57	7·15	0·94
32 . . .	6·29	6·53	1·04	8·73	8·22	0·94
40 . . .	..	..	..	10·01	9·48	0·94

TABLE V

Limes (Citrus aurantifolia ; *variety, Kagadi*)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big 50-60 gm. (53)	Small 20-25 gm. (23)	Small/Big	Big 50-60 gm. (54)	Small 20-25 gm. (24)	Small/Big
4 . . .	5·94	8·01	1·35	2·96	4·16	1·40
8 . . .	10·33	13·24	1·28	5·18	7·25	1·40
12 . . .	13·00	16·37	1·26	6·52	8·86	1·36
16 . . .	16·77	20·94	1·25	8·63	11·49	1·33
20 . . .	19·36	24·07	1·24	10·36	13·78	1·33

TABLE VI

Mosambi (Orange Mozambique)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big 280-300 gm. (288)	Small 190-210 gm. (202)	Small/Big	Big 260-270 gm. (265)	Small 170-190 gm. (180)	Small/Big
9 . . .	1·61	1·79	1·11	1·96	2·32	1·18
17 . . .	2·88	3·27	1·13	3·32	3·92	1·18
25 . . .	4·08	4·66	1·14	3·95	4·70	1·19
33 . . .	5·28	5·99	1·13	4·54	5·44	1·20

TABLE VII

Malta orange (variety, Blood Red)

Number of days of storage	Percentage loss in weight								
	35°F.			40°F.			45°F.		
	Big 260-280 gm. (270)	Small 140-180 gm. (166)	Small/Big	Big 255-295 gm. (271)	Small 130-170 gm. (152)	Small/Big	Big 260-300 gm. (280)	Small 140-180 gm. (163)	Small/Big
16 . .	4·91	6·24	1·27	7·20	7·44	1·03	7·28	8·44	1·16
34 . .	10·02	12·09	1·21	13·68	15·77	1·15	14·20	16·60	1·17
50 . .	14·37	16·89	1·18	19·67	23·19	1·18	20·13	23·44	1·17
68 . .	19·23	21·73	1·13	26·07	30·55	1·17	27·06	29·90	1·11
85 . .	23·42	25·61	1·09	31·51	36·35	1·15	32·74	35·63	1·09

TABLE VIII

Nagpur orange

Number of days of storage	Percentage loss in weight															
	35°F.			40°F.				45°F			52°F.			68°F.		
	Big 200-230 gm. (218)	Small 130-160 gm. (143)	Small/Big	Big 220-270 gm. (234)	Small 130-160 gm. (148)	Small/Big	Tight-skinned 130-160 gm. (147)	Big 190-230 gm. (208)	Small 140-180 gm. (159)	Small/B	Big 195-225 gm. (207)	Small 130-170 gm. (149)	Small/Big	Big 210-230 gm. (221)	Small 130-160 gm. (146)	Small/Big
9	1·45	1·56	1·08	1·51	2·17	1·44	1·73	1·53	1·91	1·25	2·40	2·72	1·13	4·03	4·27	1·06
17	2·44	3·03	1·24	2·73	3·91	1·43	3·17	2·70	3·65	1·35	3·95	4·52	1·14	6·14	6·46	1·05
26	3·59	4·53	1·26	4·17	6·00	1·44	4·88	3·97	5·56	1·40	3·59	6·38	1·14	8·24	8·97	1·09
34	4·63	5·77	1·24	5·46	7·88	1·44	6·44	5·19	7·25	1·40	7·10	8·17	1·15	...	...	...
42	5·68	7·12	1·25	6·77	9·73	1·44	8·00	6·43	8·92	1·39	8·59	9·92	1·15	...	...	...
51	7·10	9·35	1·31	8·32	11·88	1·43	9·73	7·87	10·84	1·38	10·34	12·01	1·16	...	...	...
59	8·11	10·14	1·25	9·57	13·61	1·42	11·23	9·09	12·50	1·38	11·90	13·62	1·15	...	...	...
67	9·35	11·49	1·23	10·40	15·35	1·48	12·74	10·30	14·12	1·37	13·53	15·04	1·11	...	...	...
77	10·81	13·13	1·21	12·40	17·48	1·41	14·47	11·78	16·07	1·36	15·57	17·06	1·10	...	...	...

TABLE IX

Thickness of the skin of big and small fruits

Name of fruit	Thickness in cm.		
	Big	Small	Big/Small
Banana . .	0·31	0·22	1·41
Grape fruit .	0·43	0·35	1·23
Limes . .	0·12	0·09	1·42
Mosambi . .	0·38	0·28	1·36
Nagpur orange .	0·29	0·23	1·26

TABLE X

Percentage of pulp in big and small fruits

Name of fruit	Percentage of pulp		
	Big	Small	Small/Big
Banana . .	58·4	62·5	1·07
Grape fruit .	77·0	76·6	..
Limes . .	81·4	83·7	1·03
Mosambi . .	74·8	74·2	..
Nagpur orange .	74·0	77·6	1·05

TABLE XI

Rate of respiration of big and small fruits at 68°F.

Name of fruit	Parts of CO_2 per 100 gm. of fruit per 24 hours		
	Big	Small	Small/Big
mes .	32·1	38·1	1·19
osambi . .	14·5	18·0	1·24
agpur orange .	22·2	24·8	1·12

The skin of fruit plays an important part in regulating the gaseous exchange between the tissues and the atmosphere around the fruit. The absorption of oxygen and the excretion of carbon dioxide and water vapour take place through the skin by diffusion. The rate of diffusion of the gases depends on the permeability of the skin. It has been found that the thickness of the skin of small fruit was less than that of big fruit (Table IX). The rate of gaseous diffusion may, therefore, be more rapid in small fruit and consequently lead to a greater evaporation of water from the pulp tissues resulting in a greater loss in weight.

It is also possible that the greater loss in weight of small fruit may be the result of a higher rate of respiration. The small fruit may respire more than the big fruit on account of a relatively larger surface per unit volume or more rapid diffusion of gases through the thinner skin. The higher rate of respiration may be partly due to a larger proportion of pulp in small fruit. It has been found that in the case of bananas, limes and Nagpur oranges, the percentage of pulp in small fruit was higher than that in big fruit (Table X). The percentages of pulp in Mosambi and grape fruit of the two sizes were practically equal.

Gustafson [1929] conducted some experiments with tomatoes to determine whether the size of the fruit exerted any influence on the rate of respiration, but nothing definitely was ascertained though, in some cases, it seemed that larger fruits respired less per gram of material than smaller fruits of the same age. In these experiments the determination of the rate of respiration at 68°F. of fruits of the two sizes showed that the rate of respiration was higher in the case of small fruit (Table XI). It is necessary, however, to consider these values with some reservation as it is very difficult to get fruit of two sizes at the same stage of physiological development for proper comparison and considerable variation often exists among individual fruits.

The values obtained for the small/big ratio in the case of Nagpur oranges (Table VIII) stored at different temperatures were interesting. The values at 40° and 45°F. were high and approximately equal. The rates of loss in weight at these two temperatures were also nearly equal. The value of the ratio was lower at 35°F. and equalled the ratio of the skin thicknesses. The value at 52°F., as previously mentioned, was equal to the surface ratio, while the value at 68°F. approximated the pulp ratio. Loftfield [1921] has shown that the temperature influences the stomatal movement, the rate of movement increasing with temperature. If it could be assumed that the stomata were wide open at 68°F. and a free exchange of gases took place the quantity of the pulp would determine the rate of loss in weight. At 52°F. the stomata might be open in the normal way and an easy diffusion of gases would take place, the rate of loss in weight depending on the area of the surface exposed. At 40° and 45°F. the stomata might be just open so that the thickness of the skin determined the rate of exchange of gases and the value of the ratio small/big represented the combined effect of the surface, pulp and thickness of the skin ratios. In Nagpur oranges, which are ordinarily puffy and loose-skinned, there are some fruits which are tight-skinned and more compact. The rate of diffusion of gases in such oranges is expected to be slower than that in puffy fruits. The rate of loss in weight of tight-skinned oranges was found to be less than that of puffy fruit of approximately equal volume,

In the case of the Malta orange, big fruit kept in storage a much fresher appearance than small fruit which appeared shrivelled. The skin dried up and assumed a dull colour. It is possible that the aperture of stomatal pores in the skin of small fruit may be smaller than that in the case of big fruit. The higher rate of transpiration leads to loss of turgidity of the cells which may effect a partial closure of stomata so that a major portion of the loss in weight takes place from the skin which, in the course of time, shows shrivelling.

Summary

1. The percentage loss in weight in storage at different temperatures of fruits of two sizes, big and small, has been determined. The fruits used were apples, chikoos, bananas, grape fruits, limes, Mosambi, Malta oranges and Nagpur oranges. The data showed that the loss in weight of small fruit was always greater than that of big fruit, except in the case of grape fruit at 68°F.

2. The thickness of the skin, the percentage of pulp and the rate of respiration of fruits of the two sizes have been determined. The skin of small fruit was found to be thinner than that of big fruit. In bananas, limes and Nagpur oranges the percentage of pulp in small fruit was a little higher than that in big fruit. The rate of respiration of small fruit was also greater than that of big fruit.

3. The ratio of the percentage loss in weight of small fruit to the percentage loss in weight of big fruit remained practically constant during the storage period. The value of the ratio, however, varied with the temperature of storage.

4. The higher percentage loss in weight of small fruit could be correlated in some cases to the relatively greater surface per unit volume of fruit exposed. The ratio small/big was found to be approximately equal to the surface ratio in the case of limes (stored at 45°F.), Mosambi, Malta oranges and Nagpur oranges (stored at 52°F.).

5. It has been suggested that the comparatively thinner skin of small fruit facilitated a more rapid diffusion of gases which resulted in a higher rate of evaporation of water from the pulp and possibly in a higher rate of respiration as well.

6. The difference in the values of small/big ratio obtained at different temperatures in the case of Nagpur oranges has been discussed.

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VARIETIES OF CARDAMOM IN CULTIVATION IN MYSORE

BY

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(With Plate XLVI)

Introduction

BAKER [in Hooker, 1894] and Fischer [1928] have mentioned *Elettaria cardamomum* Maton. growing in South India. They have further made mention of a single variety *E. cardamomum* Maton. var. *major* Thw. This variety has been stated to be a robust plant with leaves broader than the type and having oblong-fusiform fruits 1 in. or more long and indigenous in Ceylon [Hooker, 1892]. Thwaites gives the habitat of the variety as 'forests in the central and southern provinces, up to an elevation of 3,000 ft.'

Ridley [1912] mentions that 'there are two distinct forms or varieties of the plant, viz. var. *minus*, the Malabar cardamom, a taller plant with narrower and less firm leaves and globose fruits from 1/5 to 9/10 in. long, greyish yellow or buff in colour. This is confined to southern India. Var. *majus* with shorter stems, broader leaves and oblong fruit, from 1 to 2 in. long, and rather narrower than the Malabar fruit, distinctly three-sided, often arched and dark-greyish brown when dry, the seeds larger and more numerous, and less aromatic. This is the Ceylon cardamom and peculiar to that country.' Molegode [1938] reports that three varieties of *Elettaria cardamomum* Maton. are found in Ceylon. One of these is indigenous to Ceylon. The cultivated varieties, Malabar and Mysore, appear to have been introduced from India. The Malabar variety is described : ' Leaves silky on the under-surface ; recemes arise from the base of the stem and creep on the surfae of ground around the clumps ; fruits or capsules angled, shorter and more globular than the Mysore type.' The Mysore variety is described : ' Leaves larger with a coarser under-surface, not silky but hard and smooth ; racemes rise erect ; fruits oblong and larger than those of the Malabar type.'

Material and methods

A number of collections of cardamoms from several localities in South India are growing on the Government Coffee Experiment Station, Balehonnur. The collections were made by Mr K. H. Srinivasan, M.A., B.Sc. (Edin.). I began studying these with a view to classifying them. During the course of study the principal cardamom-growing areas in Mysore that are round about Manjarabad were visited and the cardamoms growing there were studied. As a result it was observed that though cardamoms growing in Mysore belong to the species *Elettaria cardamomum* Maton. there are well-marked differences suggesting the existence of distinct varieties. These could not be classified according to the described varieties. Further, it was observed that the description of the species also required certain changes. In the present paper

FIG. 1. *Elettaria cardamomum* Maton.—general habit

FIG. 2. *Elettaria cardamomum* Maton.—fruiting habit

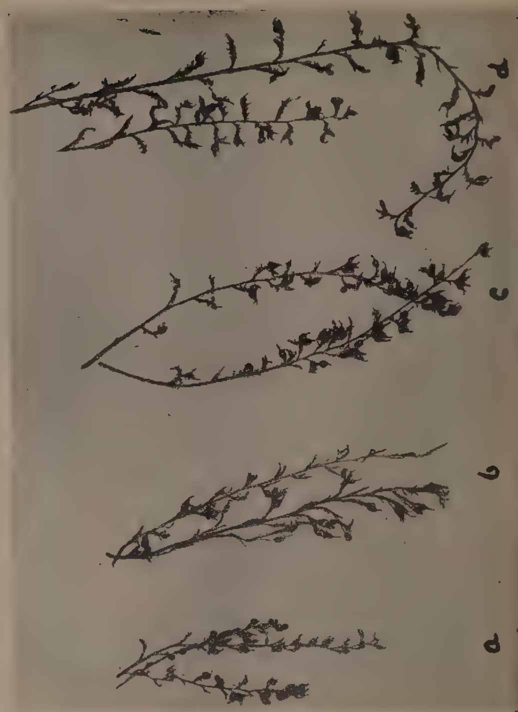

FIG. 3. Panicles of (*a*) *Elettaria cardamomum* Maton; (*b*) var. *laxiflora*; (*c*) var. *mysorensis*; (*d*) var. *major*

three varieties have been described and some changes in the description of *Elettaria cardamomum* Maton. given in Hooker [1894] and Fischer [1928] are introduced.

All the detailed observations were done on plants growing on the Station side by side under identical climatic conditions and these were supplemented by general observations on plants in the cardamom estates round about Manjarabad.

Description

Elettaria cardamomum Maton. (Plate XLVI, figs. 1, 2, 3*a*).—Perennial herb; rootstock horizontal ; leafy stem tall, 5 ft.-11 ft. high ; leaves distichous, linear lanceolate, acuminate, sessile or shortly petioled up to 0·75 in. ; glabrous above, glabrous or softly pubescent beneath, 1 ft.-2·5 ft. long, 1·75 in-4·75 in. broad ; margin wavy. Panicles produced direct from the rootstock, flexuous, decumbent, several to one leafy stem, up to about 2 ft. long ; bracts linear-oblong, obtuse, about 1·5 in. long ; flowers produced in 2 to 12 flowered short racemes 0·5 in.-3·5 in. long ; bracteolate, shortly pedicelled. Calyx membranous tubular, shortly three lobed, 0·5 in.-0·7 in. long, persistent. Corolla tube cylindric, white, shortly exserted, 0·75 in. long ; lobes spreading, mid-lobe oblong, convex ; lateral narrower ; lobes 0·5 in. long. Lip oblong-obovate, longer than the corolla lobes, 1 in. × 0·72 in., base cuneate, margin wavy ; white striped with violet ; lateral staminodes minute teeth ; two staminodes at the base of the corolla tube ; stamen with a short filament ; anther not crested, its cells contiguous ; longitudinally dehiscing. Ovary three celled ; ovules many 2-seriate in each cell, axile ; style filiform, 1·2 in. long ; stigma small, funnel shaped, ciliate. Fruit a sub-globose, sub-trigonous, coriaceous, indehiscent capsule, 0·4 in.-0·7 in. × 0·3 in.-0·5 in., striate, pale yellow when ripe ; each cell contains three to eight seeds. Seeds obovoid, angular by compression, transversely wrinkled, aromatic, arillate.

Var. *laxiflora* (Plate XLVI, fig. 3*b*).—Leafy stemup to 14 ft. Leaves 11in.-2·75 ft. × 1·5 in.-5·5 in., shortly petioled or not, glabrous on both sides Panicles flexuous, up to 4·25 ft. long, lax, decumbent. Flowers produced in 4 to 40 flowered short lax racemes, 0·5 in.-5 in. long. Pedicel up to 1 in. long. Capsules very variable, oblong to oblong-fusiform, 0·5 in.-1 in. × 0·3 in.-0·5 in. ; each cell contains two to nine seeds.

Var. *Mysorensis* (Plate XLVI, fig. 3*c*).—More robust. Leafy stem up to 17 ft. high. Leaves 1·2 ft.-2·6-ft. × 2 in.-6·25 in., glabrous on both sides, or glabrous above and pubescent beneath, petiole up to 1·5 in. long. Panicles flexuous or not up to 4·75 ft. long, erect or decumbent. Flowers produced in 4 to 35 flowered short racemes, 0·5 in.-6·5 in. long. Lip broader 1·2 in. × 1 in. Capsule bigger 0·5 in.-0·8 in. × 0·35 in.-0·6 in., distinctly three-angled ; each cell contains three to nine seeds.

Var. *major* Thw. (Plate XLVI, fig. 3*d*).—More robust. Leafy stem up to 18 ft. high. Leaves 1 ft.-2·75 ft. × 2 in.-6·5 in., pronouncedly petioled, petiole up to 2 in. long, glabrous on both sides. Panicles not flexuous, up to 4·5 ft. long, erect. Flowers produced in 6 to 40 flowered short racemes 0·5 in-4·5 in. long. Lip broader 1·2 in. × 1 in. Capsule oblong-fusiform, 0·5 in.-0·8 in. × 0·3 in.-0·45 in. ; each cell contains three to six seeds. Seeds are larger and slightly flatter.

Habitat description

The varieties are cultivated to a greater or lesser extent in almost all the estates in Mysore. Var. *laxiflora* has not been obtained from outside Mysore. It has been observed growing in the cardamom estates round about Manjarabad. Var. *major* Thw. is stated by planters as obtained either from Ceylon or from Annamalais. At the Station, plants have been raised from seeds obtained from Annamalais, Travancore and estates in Mysore. All these are similar and belong to the variety *major* Thw. Plants of var. *Mysorensis* have also been raised from seeds obtained from several estates in South India, so that the habitat of the variety may be said as South India and under cultivation.

Discussion and conclusions

There are differences between the description of *Elettaria cardamomum* Maton. by Baker [in. Hooker, 1894] and Fischer [1928], and the description in the present paper. They mention that the species has leaves that are pubescent beneath ; bracts two to seven flowered ; seeds not arillate. I have found that the leaves are either glabrous or pubescent beneath ; flowers are produced in 2 to 12 flowered short racemes in the panicles ; seeds are arillate. Further, the presence of two staminodes at the base of the corolla tube has been reported by the author [Narasimha Swamy, 1937]. It is observed that Malabar cardamom of Molegode [1938] corresponds to the type described.

Var. *major* Th. has been mentioned by Baker [in Hooker, 1894] and Fischer [1928]. The present description of the variety differs in having 6 to 40 flowered short racemes in the panicle and fruits that are 0·5 in.-0·8 in. long.

Var. *Mysorensis* appears to correspond with the Mysore cardamoms of Molegode [1938] though the former differs in having leaves that are glabrous or pubescent beneath and panicles that are erect or decumbent.

Var. *laxiflora* appears to have not been described so far. Glabrous leaves, lax decumbent panicles having 4 to 40 flowered short lax racemes that have flowers with long pedicels, and fruits which are often elongated clearly distinguishes this variety.

Summary

Elettaria cardamomum Maton. var. *laxiflora*, var. *Mysorensis*, var. *major* Thw. have been described.

Acknowledgements

I am deeply indebted to Mr K. H. Srinivasan, M.A., B.Sc. (Edin.), for kindly allowing me to make use of the material collected by him, and for the encouragement given by him and Mr W. W. Mayne, B.Sc., during the course of the study.

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RESEARCH NOTE

CHROMOSOME NUMBER IN BAMBOO (*DENDROCALAMUS STRICTUS*)

BY

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(Received for publication on 14 August 1939)

(With one text-figure)

DURING 1938-39, a few plants of *Dendrocalamus strictus* along the road-sides of the Maharaj Bagh Gardens, Nagpur, exhibited flowering. Seeds were collected from these plants in the beginning of February 1939 for chromosome studies. There is no record of such observations in this species in any Indian publication.

The seeds were kept for germination in two lots, i.e. on 2nd and 4th of March respectively, on moist filter papers in Petri dishes. The first lot showed cent per cent germination, while the second lot only 67 per cent. In three days the root tips were ready for fixation. The following Navashin's solution, modified in our laboratory, was used with satisfactory results, followed by the iodine-gentian violet staining. Paraffin sections were cut at 15 μ.

Chromic acid 1 per cent . . .	5 c. c.
Formalin 20 per cent	3 c. c.
Glacial acetic acid	1 c. c.

Seventy-two chromosomes were distinctly observed on the metaphase plates of the root-tip cells (Fig. 1). The number was confirmed from several plates.

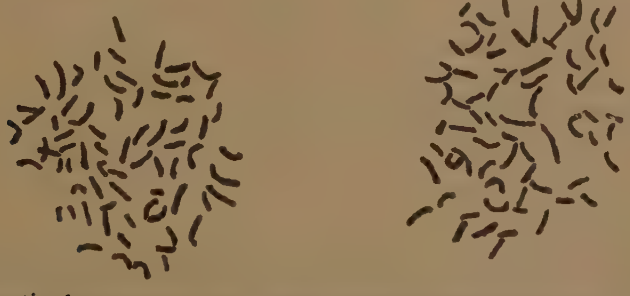

Fig. 1. Somatic chromosomes from *Dendrocalamus strictus* ($2n=72$) ($\times$ 3,200)

REVIEWS

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THE Imperial Forestry Bureau is publishing a quarterly journal entitled *Forestry Abstracts*. This provides a survey in English of the current literature of forestry from all parts of the world. Each issue normally includes special reviews of the literature of particular subjects, notes on annual reports, and abstracts classified by subject. In the abstracts the aim is to epitomize the contents of each paper so as to enable the reader to judge of its value as a contribution to knowledge. In addition to papers in English, French and German, attention is also directed to those published in the less familiar languages.

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